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AIR-GROUND ENGAGEMENT MODELS REVIEW.(U)
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March 1973

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This technical review of air-ground engagement models was performed to assist model users in determining the proper application of these models and the efficient allocation of available modeling resources. The objectives of the review were to: identify the strengths and weaknesses of each model, develop insights into the kinds of analytical problems to which each model can be most effectively applied, develop recommendations for improving each of the models, as appropriate, to include input data, logic, and employment of the model, determine

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resource requirements for each model, surface improved model techniques, and develop a rational program for air-ground engagement models to include requirements for research, data acquisition, continuing maintenance, conversion to different computers and documentation.

The models reviewed were CARMONETTE V, EVADE II, and GLOBAL. The factors considered in selecting these models were the extent of their current use in Army studies, their two-sided nature, their level of resolution, their play of a multiplicity of weapons, and their existing proposals for improvements. The CARMONETTE V Monte Carlo computer simulation was developed by the Research Analysis Corporation to evaluate combat engagements between forces of up to battalion size. The EVADE II deterministic computer simulation was developed by the U.S. Army Materiel Systems Analysis Agency to evaluate the attrition of both ground and air participants as multiple aircraft fly missions over deployments of air defense weapons. The GLOBAL Monte Carlo computer simulation was developed by Stanford Research Institute to evaluate combat engagements of attacking air or ground units against defending ground units.

The review was accomplished by analysis teams from the U.S. Army Management Systems Support Agency (USAMSSA) and the Models Coordinating Group, Office of the Coordinator Army Studies, Office of the Assistant Vice Chief of Staff of the Army. Assisted by the model developers, the authors conducted a line-by-line examination of each program. The reviews investigated the structure and the submodels of each model.

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EXECUTIVE SUMMARY

This technical review of air-ground engagement models was performed under the supervision of the Assistant Vice Chief of Staff of the Army to assist model users in determining the proper application of these models and the efficient allocation of available modeling resources. The objectives of the review were to:

- Identify the strengths and weaknesses of each model.

- Develop insights into the kinds of analytical problems to which each model can be most effectively applied.

- Develop recommendations for improving each of the models, as appropriate, to include input data, logic, and employment of the model.

- Determine resource requirements for each model.

- Surface improved model techniques.

- Develop a rational program for air-ground engagement models to include requirements for:

  Research

  Data acquisition

  Continuing maintenance

  Conversion to different computers

  Documentation

The models reviewed were CARMONETTE V, EVADE II, and GLOBAL. The factors considered in selecting these models were the extent of their current use in Army studies, their two-sided nature,

their level of resolution, their play of a multiplicity of weapons, and their existing proposals for improvements. The CARMONETTE V Monte Carlo computer simulation was developed by the Research Analysis Corporation to evaluate combat engagements between forces of up to battalion size. The EVADE II deterministic computer simulation was developed by the U.S. Army Materiel Systems Analysis Agency to evaluate the attrition of both ground and air participants as multiple aircraft fly missions over deployments of air defense weapons. The GLOBAL Monte Carlo computer simulation was developed by Stanford Research Institute to evaluate combat engagements of attacking air or ground units against defending ground units.

The review was accomplished by analysis teams from the U.S. Army Management Systems Support Agency (USAMSSA) and the Models Coordinating Group, Office of the Coordinator of Army Studies, Office of the Assistant Vice Chief of Staff of the Army. Assisted by the model developers, the authors conducted a line-by-line examination of each program. The reviewers investigated the structure and the submodels of each model. The submodels that comprise the event generation and the interaction assessment processes were reviewed in detail. Event generation consists of route selection, line-of-sight (LOS) determination, target acquisition, target tracking, suppression, response to fire and firing decision. Clearly these processes depend on a considerable amount of subjective input data for simulating the execution of doctrine, as well as field test data to represent the many psychophysical processes of the participants. The interaction assessment process consists of the firing accuracy and attrition submodels. These submodels are generally based on more extensive field tests and a rich heritage of previously validated analytical effort.

FINDINGS

GENERAL

The findings of the review are discussed below. The weaknesses and strengths ascribed to each model, plus additional material from the body of the report, form the basis on which the conclusions of this review are drawn.

• At the time of the review all three models lacked complete, accurate documentation packages. Specific weaknesses in documentation are pointed out in the main report. CARMONETTE documentation has been a piecemeal effort over several years and requires consolidation, updating, and correction of errors. New EVADE documentation has recently been published in final form. GLOBAL documentation was nonexistent with the exception of general abstracts on the model. A contract to accomplish the GLOBAL documentation is currently being executed.

• The models reviewed do not fit into an overall hierarchy of models which is necessary to give logical consistency to analyses of Army air-ground interactions. The results of model manipulations at one organizational level should be reflected as input to analyses in higher level studies. This need to feed information up and down a models chain is well recognized, but very few links between levels of models truly exist at this time.

CARMONETTE-STRENGTHS

• The use of preprocessors permits good flexibility in setting up different treatments and the use of postprocessors permits the user to tailor the output to his specific needs.

• CARMONETTE permits movement of the defender as well as the attacker ground units.

• CARMONETTE is free of the requirement for precalculation of line-of-sight on flight paths, making evasion and alternate flight paths possible using decision logic within the game.

• CARMONETTE effectively plays suppression of ground units.

• Dynamic response to fire is simulated in CARMONETTE.

CARMONETTE-WEAKNESSES

N/A

• The storage of data by CARMONETTE is very efficient, although highly machine dependent. Transfer of the model to a different computer would require redesign of the data storage and complete reprograming of the model.

• CARMONETTE does not adequately treat the attrition of scout and transport helicopters.

• There is no queuing of requests for artillery and air support. If resources are not available, the request is dropped by the supporting element.

• If an aircraft altitude change is ordered between two grids, the change takes place in zero time while the aircraft is in the center of the initial grid; the move time to the final grid is computed for a constant rate of change of altitude.

• Movement can only be parallel to a coordinate axis or diagonal (45 degrees). This is not generally the best or mose realistic route. [The developers state that a recent change now provides for a more direct route. This change was made after the model was examined for this report.]

• LOS from aircraft to ground weapons is not checked along the aircraft's flight path when the aircraft proceeds to an ordered destination. In effect, flight is assumed to be at treetop level and far removed from enemy units. This logic prevents the realistic play of observation type aircraft. [The developers state that LOS is now checked at each boundary crossing. This change was made after the model was examined for this report.]

• The CARMONETTE simulation of the pop-up tactic has some questionable logic pertaining to checks of LOS while rising and knowledge of the required pop-up altitude in advance.

EVADE II - STRENGTHS

• The aircraft attrition routine is very detailed and may be suitable for producing input data for use by other models.

• EVADE II is the only one of the three models to include true tracking of a target aircraft by an air defense weapon system.

• The firing accuracy calculation in EVADE includes a LOS check during projectile flight.

EVADE II - WEAKNESSES

• EVADE II input routines perform very limited editing of input data by checking the bounds of selected variables. The input routines

terminate processing upon detection of the first erroneous datum rather than processing the entire data base and flagging errors.

- EVADE II checks LOS at the end points of each flight path segment and then interpolates to find a point between them where LOS is assumed to be broken or established. This could produce a false LOS history along a path segment if the segment is too long.

- EVADE II does not have an air-to-ground detection submodel suitable for air-to-ground evaluations. Field test data are used to introduce delays in detecting ground targets.

LIMIT

- EVADE II does not provide output to show when the attacking aircraft are so numerous as to leave some that cannot be assigned to available ground weapons.

GLOBAL-WEAKNESSES

- The GLOBAL model has serious structural limitations:

  Only four aircraft and 32 ground weapon sites.

  Stationary defenders.

  Preplanned routes, precomputed line-of-sight, time sequenced design.

  No transfer of target information between units.

  Rudimentary target tracking.

  Simple firing decision.

- GLOBAL users must input many of the variables CARMONETTE and EVADE calculate. Pregame data preparation is extensive and complex, especially in preparation of attacker path segments and subjective visibility or exposure levels.

- Each executable statement in the GLOBAL program that requires data from storage necessitates a highly complex data unpacking logic. The data handling techniques utilized in GLOBAL are specifically designed for a

Control Data Corporation computer (60 bits per word). Conversion to a different computer would be extremely difficult, requiring almost complete reprograming.

- The model provides no increase to the probability of detection of those targets previously detected and then later masked.

- GLOBAL attrition logic processes all units in a fixed sequence after each time increment of play. This can introduce bias for the longer time increments, e.g., by crediting kills to units which may have already been killed in the same time increment.

CONCLUSIONS

GENERAL

The EVADE II model is a very high resolution simulation and includes much more detail than the high resolution CARMONETTE V or GLOBAL. The CARMONETTE V detection routines VISDET, IMADET and RADAR are out of balance with the level of detail in the rest of the model and are comparable to the level of detail in EVADE II.

CARMONETTE

- The CARMONETTE V model permits representation of many of the factors relevant to the aerial attack of ground maneuver units up to battalion size, to include artillery suppression of air defense weapons and simultaneous ground-to-ground combat.

- The CARMONETTE V model has an event generation structure that will permit growth of its capability.

- The CARMONETTE V model is sufficiently economical for routine use.

EVADE

- The EVADE II model is the best model for detailed evaluation of ground-to-air attrition.

- The EVADE II model is too expensive for routine use of its full capability. However, reducing its capability by bypassing subroutines permits economical operation.

- The EVADE II model is not suitable for studies involving the aerial attack of maneuver units which are engaged in ground-to-ground combat. It could be used to resolve the air-to-ground and ground-to-air portions of such studies, however.

GLOBAL

- The GLOBAL model is not suitable for studies involving the aerial attack of maneuver units engaged in ground-to-ground combat.

- The GLOBAL model has very little growth potential without major restructuring.

RECOMMENDATIONS

Based solely on the three models studied, it is recommended that:

GENERAL

The air-ground engagement model hierarchy should be initiated by developing interfaces between EVADE II and CARMONETTE V. The GLOBAL model should not be considered for inclusion in this hierarchy. The proponents of EVADE II and CARMONETTE V should collaborate on development of these interfaces and insure the compatibility of their models within the concept of a models hierarchy.

CARMONETTE

- CARMONETTE V should be retained and applied to studies involving aerial attack of maneuver units of up to battalion size.

- CARMONETTE V should be redocumented at once.

- CARMONETTE should be improved as follows:

  Requests for artillery and air support should be queued for some period of time after the initial call. NO

Changes in aircraft altitude should be accomplished over time rather than in zero time. No

Moving aircraft should perform LOS checks upon boundary crossing. [Correction was made, according to the developer, after the model was examined for this report.] ok

The rationale for helicopter "pop-ups" should be reconsidered. LOS checks should be performed at incremental altitudes. Final altitude should not necessarily be predetermined. yes

The MOVE routine should be modified to allow more direct routes. [Correction was made, according to the developer, after the model was examined for this report.] ok

The RADAR, VISDET, and IMADET routines should be replaced by simplified routines based on the output of the EVADE II detection models or other validated models. yes

The coding should be updated to utilize available software features. In particular, the exponential approximation used in the computation of hit probabilities should be replaced by the FORTRAN library function. No

The number of grid squares should be increased to permit larger scenarios without loss of resolution. ✓ yes

EVADE

- EVADE II should be retained and applied to studies involving detailed evaluation of ground-to-air attrition.

- EVADE II should be utilized to produce input data for calculation of hit probability within CARMONETTE and other lower resolution models.

- EVADE II should be improved as follows:

  The entire data base should be reviewed during preprocessing so that erroneous data are flagged on each pass through the editing routines.

  An air-to-ground detection routine should be developed and included in the model.

  Wind speed effects, wind direction, and other environmental factors should be considered to improve the acoustic detection routine.

  The rationale for determining the suppressive delay of ground unit fires should be developed and documented.

  Saturation of air defense capability should be taken into account.

GLOBAL

- No further improvement of the GLOBAL model should be initiated.

- The current GLOBAL documentation effort should be completed.

- Future use of GLOBAL should be limited to support of the Advanced Attack Helicopter Project only until such time as CARMONETTE and EVADE can be used for this purpose. yes

INTRODUCTION

GENERAL

This detailed technical review of air-ground engagement models was undertaken by the Models Coordinating Group (assigned to the Office of the Coordinator of Army Studies, Office of the Assistant Vice Chief of Staff) under the supervision of the Army Study Advisory Committee (ASAC). During the ASAC review of the FY 73 Army Study Program a number of studies in the area of attack, scout, and observation helicopters were found to be recently completed, continuing, or proposed. Each of these studies used, were using, or planned to use a different model. The Chairman of the ASAC deemed it appropriate to review several of these models to insure their proper application and the efficient allocation of available modeling resources.

The objectives of this review are to:

- Identify the strengths and weaknesses of each model.

- Develop insights into the kinds of analytical problems to which each of the models can be applied most effectively.

- Develop recommendations for improving each of the models, as appropriate, to include input data, logic, and employment of the model.

- Determine resource requirements for each model.

- Surface improved modeling techniques.

- Develop a rational program for air-ground engagement models to include research requirements, data acquisition requirements, requirements for continuing maintenance of specific models, requirements for conversion to different computers, and requirements for documentation.

Air-ground engagement models include models of the interaction of aerial weapons systems and ground targets as well as air defense weapons systems and aerial targets. The models identified to be reviewed include:

BONDER AIRCAV	(VECTOR RES/CDC)
CARMONETTE V	(RAC/ACSFOR, CDC)

DYNTACS-X	(OSU/CDC, AMC)
EGLIN-P001	(USAF)
EVADE II	(AMC)
EVADES III	(GE TEMPO)
FAIRPASS	(USAF)
FAST-VAL	(RAND)
GLOBAL	(SRI/CDC, AMC)
SIMFIND	(IDA/WSEG)
TACOS	(BDM/CDC, AMC)
WEAPON	(USAF)

The scope of this initial review of air-ground engagement models was narrowed to cover three models: CARMONETTE V, EVADE II, and GLOBAL. These three models were selected on the basis of several factors which make them similar in nature. The factors were:

- The models are two-sided in that red and blue units can fire at each other.

- Several weapon types can be simulated concurrently for both sides.

- Level of resolution extends down to single weapons.

- The models are operational.

- The models had been used in major studies for the Army (e.g., CARMONETTE - "Equal Cost Firepower Study," EVADE - "Air Mobility in the Mid-to-High Intensity Environment," GLOBAL - "Army Direct Aerial Fire Support System Study"). In addition, the GLOBAL model has been utilized by the Advanced Attack Helicopter Task Force and has been selected for use by the Source Selection Board for the AAH.

- Funds had been requested for proposed improvements to the models.

Similar reviews of the remaining air-ground engagement models (listed above or otherwise identified) are anticipated. This review is the first step in a total air-ground engagement model evaluation program.

METHODOLOGY

The independent analysis team approach was used in the conduct this detailed technical review.

The review consisted of six phases:

I - Organization of working group

II - Proponent presentation

III - USAMSSA review

IV - Proponent review of draft report

V - Coordination conference

VI - MCG preparation

Phase I - Study Coordinators identified technically qualified individuals for the model for which their Staff agency, command, or subordinate activity has proponency. These individuals were contacted for assistance in obtaining details about the models and in coordinating written and verbal exchanges with the model developers, when required.

The analysis teams from USAMSSA were formed during Phase I. Two analysts were assigned to each of the three models reviewed. A desired analysis plan was presented to the USAMSSA teams by the Models Coordinating Group.

Phase II - The model developers briefed the analysis teams and the Models Coordinating Group as to the general characteristics and basic logic of their model. All available documentation, program listings, and the output of an example run of each model were acquired for use of the reviewers.

Phase III - The USAMSSA analysis teams spent an approximate total of 13 technical man-months reviewing the models. An in-depth evaluation of each line of coding surfaced the details of the programs. During this phase of the review, the teams received the assistance of the model developers in explaining sundry complex functional characteristics and less obvious internal workings of each model. The teams prepared written reports of the results of their analysis, which included model description summaries, comments on the various modules of each program, and recommendations for improvements to the programs.

A strictly parallel treatment of all aspects of each model is not given in this final report. Each individual analysis team, at times, deemed it appropriate to delve deeper into certain areas than into others. Thus, direct comparisons of all aspects of the models is not uniformly possible in all cases.

Phase IV - The model proponents were given a copy of the USAMSSA team report applicable to their particular model. These reports were reviewed by the proponents to insure that no inaccuracies existed in the reports as a result of misunderstandings or outdated documentation. The model proponents prepared written comments to this end and submitted same to the Models Coordinating Group.

Phase V - A coordination conference was arranged between each USAMSSA analysis team and the appropriate model developer, moderated by the Models Coordinating Group, to further discuss apparent misconceptions. This was accomplished only after the analysis teams had an opportunity to digest the proponents' written remarks from Phase IV. Most contentious issues were resolved at these conferences. Those that were not solved have been pointed out in the final report. The Phase V coordination conference was not accomplished for the GLOBAL model since no significant conflicts resulted from the proponents' review of the USAMSSA report of that model.

Phase VI - The Models Coordinating Group analyzed, consolidated and edited the three USAMSSA reports for final publication.

MODEL DESCRIPTIONS

A summary of each model chosen for review follows.

CARMONETTE - The CARMONETTE V Monte Carlo computer simulation was developed by the Research Analysis Corporation (now the Operations Analysis Division of General Research Corporation) to evaluate combat engagements between air and ground units. Ground-to-ground action is also played by CARMONETTE but is not considered in this report. Up to a reinforced battalion size force can be represented on each side, each with up to 48 squad or platoon weapon units. Each unit may have up to four types of weapons. These weapon types may be indirect fire or direct fire weapons and each type can use two types of ammunition.

The battlefield is represented by an array of variable size grid squares; each individual square being described by six numbers representing elevation, height of vegetation, on-road trafficability, off-road trafficability, cover, and concealment. Line-of-sight is calculated dynamically each time a unit crosses a grid boundary.

CARMONETTE is a critical-event-sequenced simulation of the activities of movement, target acquisition, communications, and weapon employment. When a unit comes within line-of-sight of an enemy unit, it has a probability of acquiring information about the enemy as a target. The information it may acquire ranges from none to full knowledge of the exact location and nature of the enemy unit. If the unit gets sufficient information and has an appropriate order, it will select weapons and ammunition and take the enemy under fire. A weapon is simulated in terms of its rate of fire and its maximum range. The effects of a projectile are simulated by tables giving the probabilities that it will hit what it was aimed at as a function of the range and the size of the target and by further tables giving the probability that it will kill the target if it hits it. Explosive projectiles are characterized in terms of their lethal areas against various targets. Ground vehicles are described on the basis of their average rates of movement under various conditions and in terms of their vulnerability to different kinds of weapons. Aircraft are characterized by their vertical and horizontal components of velocity and their vulnerability. Firing may be terminated by lack of ammunition, loss of target information, death of the firing unit, known death of the target unit, or expenditure of an ordered amount of ammunition or time.

This model is presently operational on computers at Fort Leavenworth for the Combined Arms Combat Development Activity (CACDA), Picatinny Arsenal for the U.S. Army Electronics Command (ECOM), Fort Belvoir for Combat Developments Command (CDC), and General Research Corporation in McLean, Virginia.

EVADE - The EVADE II deterministic computer simulation was developed by the U.S. Army Materiel Systems Analysis Agency to evaluate the attrition of both air and ground participants as multiple aircraft fly missions over deployments of air defense weapons. Up to 20 routes against as many as 50 individual ground weapon sites can be

simulated. Nineteen different combinations of ground gun and fire control system types are available, from 7.62mm to 57mm. Infrared missile systems (surface-to-air) are played. Aircraft can fire 7.62mm, 12.7mm, or 30mm gun systems or the TOW missile, as appropriate.

Extensive use is made of digitized descriptions of terrain maps with superimposed vegetation. A three dimensional cartesian grid of 12.7 meter scale is utilized. The MASKPAS submodel develops line-of-sight and masking information and provides a set of punched card intervisibility histories from the digitized terrain data tapes as input to the attrition submodel. The digitized terrain maps are not used dynamically.

Each preplanned mission follows a time-dependent sequence of events. For the ground weapons these events are: unmasking, target detection (either visual, acoustic, infrared, or radar), acquisition, weapon system reaction time, target approaching maximum effective range, projectile or missile time of flight, arrival at the first intercept point, and subsequent accumulation of probability of kill. This process continues until the target becomes masked, goes into a dead zone, is suppressed, is killed, runs out of ammunition, or goes out of range. For the aircraft weapons, the sequence is as follows: the pilot notes the receipt of fire or detects a ground target, his reaction time elapses, he fires his weapon, time-of-flight elapses, and kill probability accumulates until the engagement is terminated. Great detail is possible in the aircraft vulnerability portion of EVADE II, with components (engine, pilot, hydraulics, etc.) treated separately, if desired, and with vulnerable areas being varied according to the aspect angle from the weapon site. Appropriate combination of all of the component damage probabilities can then yield aircraft attrition probabilities in several categories, such as crash, forced landing and abort. The time history of probability of kill for each element in the simulation is made available to the user of EVADE II. The model is useful as a relative survivability indicator for obtaining a first-order estimate of the practicality or adequacy of flight paths, weapon deployments, tactics, equipment, etc.

EVADE II is operational on the U.S. Army Aberdeen Research and Development Center BRLESC computer and at the U.S. Air Force Systems Command, Foreign Technology Division, Wright-Patterson AFB.

GLOBAL - The GLOBAL Monte Carlo computer simulation was developed by the Stanford Research Institute to evaluate combat engagements between attacking air or ground units and defending ground units. Inclusion of both air and ground attack units is provided, but this feature is as yet untested. This report discusses only the air-to-ground capability of the model. Up to four aircraft of distinct types and on separate routes can be played against 32 ground weapon sites. The number of possible distinct weapon types for both air and ground units is 18. The defenders may change to new fixed positions as a response to fire, depending upon input fire intensity thresholds and probabilities for displacement. Thus the ground units can be considered quasi-stationary.

A three dimensional cartesian grid of optional scale is utilized. (A 10 meter grid square has been used in recent helicopter-ground simulations.) Intervisibilities between opposing units at all points of the game are precomputed and stored. Thus the topographic relief data for the grid squares are not used in the program.

The play proceeds in time sequence with defender units fixed on the grid and attackers starting at the initial points on their routes. The attack routes run from point to point across the grid in a series of straight line route segments. A detailed pregame map exercise is carried out to develop the attackers' paths, considering vehicle or aircraft performance characteristics, tactics, intervisibility, and preplanned stops or maneuvers. The paths finally input consist of straight line segments, each segment having constant properties (speed, direction, attitude, exposure level to each defender unit, time to escape to masked position, pitch and roll angles, maneuver error). Time progresses at equal intervals -- one second increments commonly used for a helicopter-ground simulation. In each time interval Monte Carlo techniques and stochastic input data determine individual element detection. Targets are selected contingent upon availability of an appropriate weapon, upon range and sector, and upon an input target priority number.

Results of a firing mission are determined by Monte Carlo techniques. Depending upon probabilities which have been input and the unit types involved, the result for a ground unit is one of the following: miss, near miss resulting in suppression, kill of one member of a weapon crew, or total kill. For an air target, the result

is miss, forced landing, mission kill, or kill. If the result is a miss, the firer will continue to fire until it runs out of ammunition or until the target is no lorger available.

The simulation is terminated when one of the attacking elements reaches the end of its predefined route, when a predetermined attrition is achieved, or when a given number of time intervals have elapsed.

The GLOBAL model is operational at Fort Leavenworth (CACDA) and at the Stanford Research Institute in Menlo Park, California.

REPORT ORGANIZATION

The remainder of this report contains more detailed information under the general headings of Model Architecture, Input and Output, Event Generation Submodels, Assessment Submodels, Summary, Findings and Conclusions, and Recommendations.

Model Architecture deals with the program organization, storage layout, and sequencing scheme. The submodels referred to are those combinations of routines which depict distinct aspects of the simulated engagements. Event Generation Submodels include route selection, line-of-sight, target acquisition, target tracking, firing decision, suppression of ground fire, and aircraft response to fire. Firing accuracy and attrition are discussed as Assessment Submodels. Each of the above functions is treated in a separate section containing parallel discussions for the three models under consideration.

The other major headings are self-explanatory.

MODEL ARCHITECTURE

By architecture is meant the design and organization of a model to include the arrangement of the functional parts as well as the decorative features.

PROGRAM ORGANIZATION

This first section under Model Architecture identifies the major submodels in the program of each model. The interactions among these submodels are illustrated in the macro flow diagrams presented. Each of the models reviewed has a patchwork quality due to a long history of improvements to adapt it to the requirements of particular studies.

PROGRAM ORGANIZATION

CARMONETTE

CARMONETTE V consists of five separate computer programs. The first two of these programs process the input data and perform file maintenance. The next program is the battle model which accepts, as input, the final output file from the second preprocessor. The battle model produces two output tape files. One of those files contains a complete history of all significant events which occurred during the battle and is called the events history. The other output file, called the umpire output, contains information about each unit's strength, position, and other unit attributes at a series of sample observations. The last two programs are used to process the output files from the battle model and produce selected reports on the results of the simulation.

A comparison of the organization of the CARMONETTE V, EVADE II, and GLOBAL models is shown in the flow diagrams in Figure 1. The structure of the CARMONETTE V Battle Model is shown in Figure 2. The program logic is identified in five basic sections: Program Control, Firing Model, Intelligence Model, Movement Model, and Decision Model.

The EXEC 2 routine searches through the units on both sides to determine the unit that has the minimum next-event time. This unit and its associated event is established as the unit to be processed and the appropriate event processing submodel is entered. The event processing submodel predicts the times of occurrence of all events following as a result of the event being processed. These event times and codes identifying them are then assigned to the affected units. The above procedure is repeated until one of the termination criteria is met.

EVADE II

EVADE II consists of two separate computer programs. The first program provides a set of punched card intervisibility histories between each weapon site and each point on the flight paths from digitized terrain data tapes. The second program evaluates the engagement problem and calculates the time history of all major events. All major events are given in chronological sequence in the normal output. A "summary print" is also available.

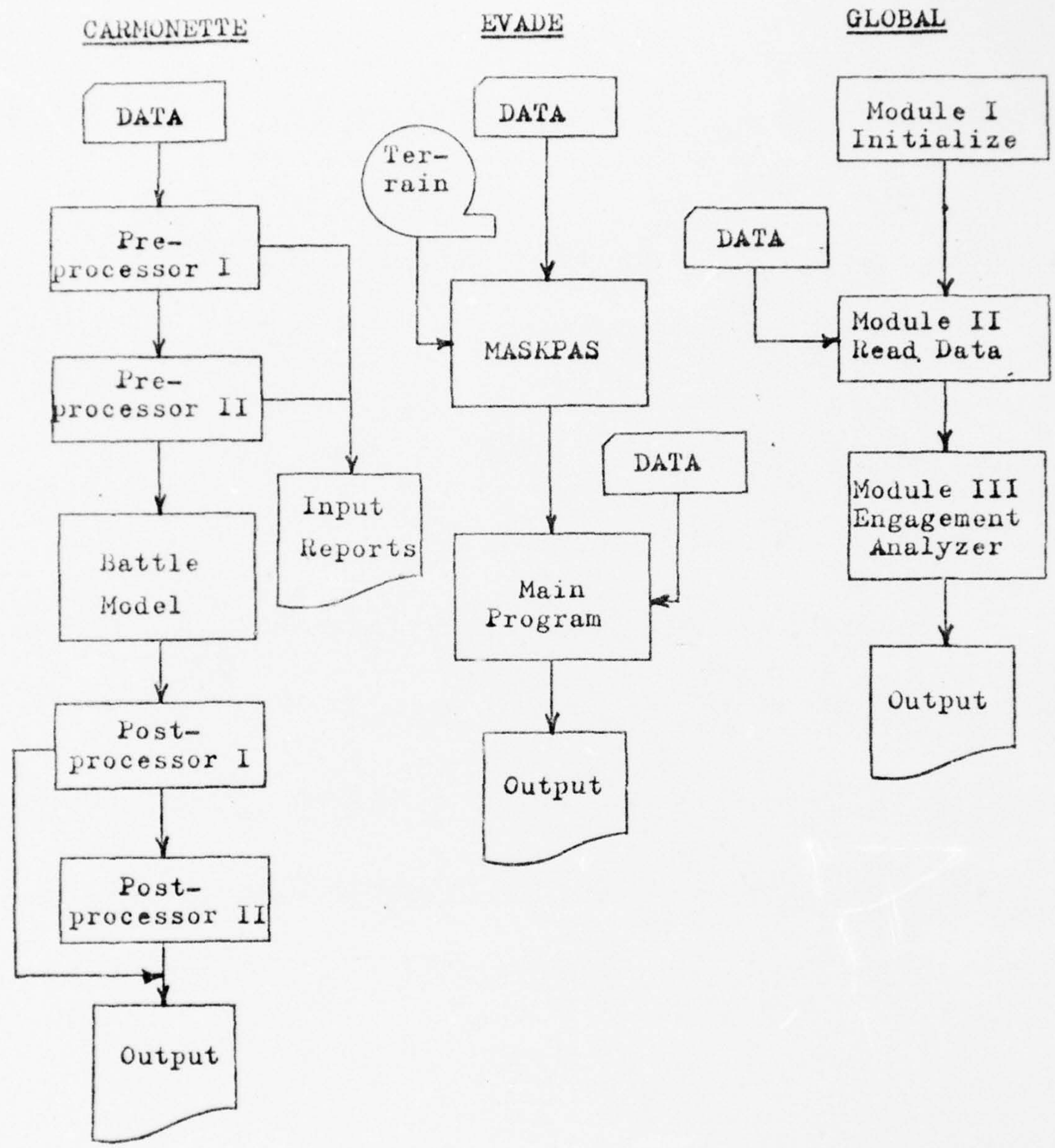


Figure 1. Basic Organization of Models

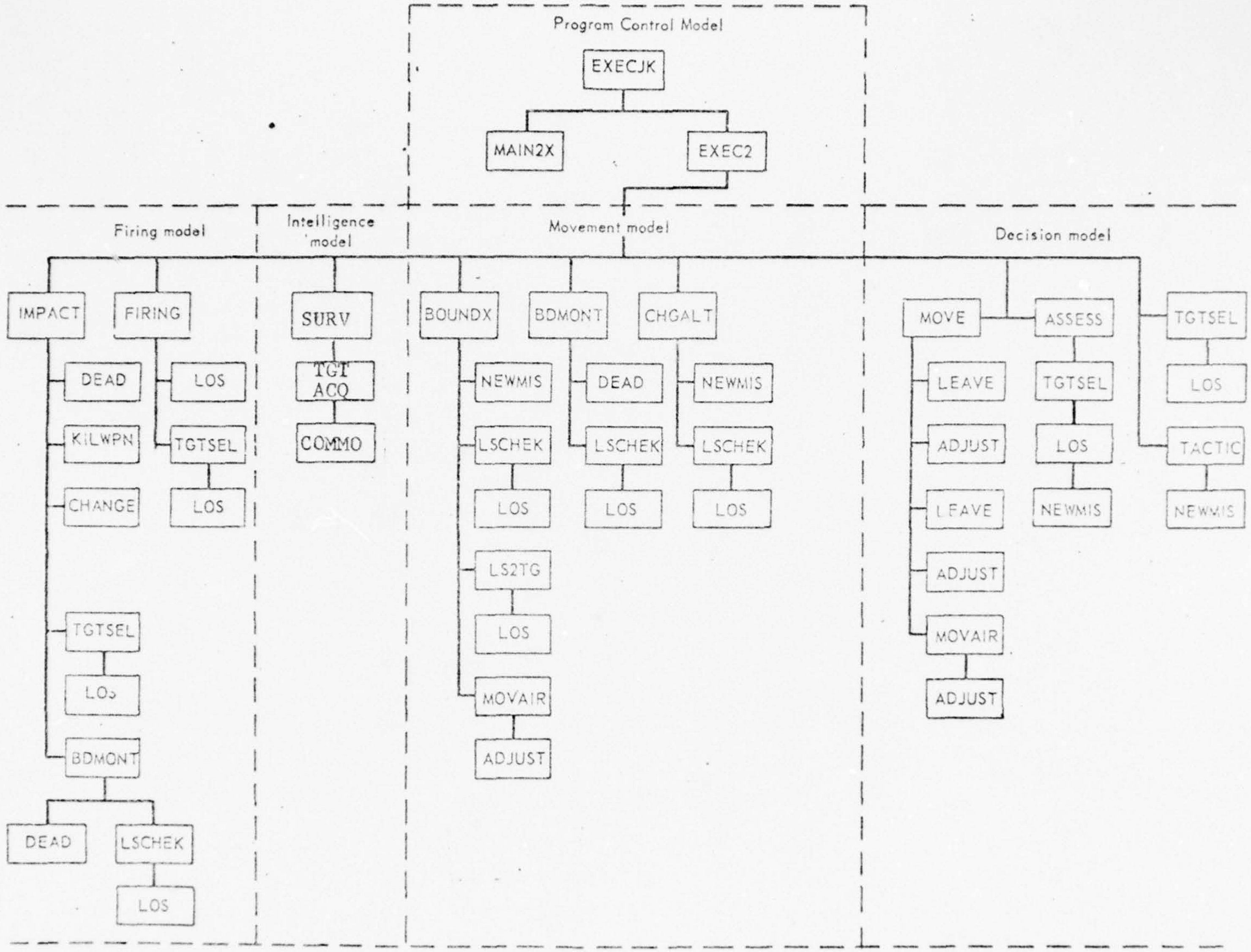


Figure 2. Organization c[illegible] CARMONETTE Battle Model

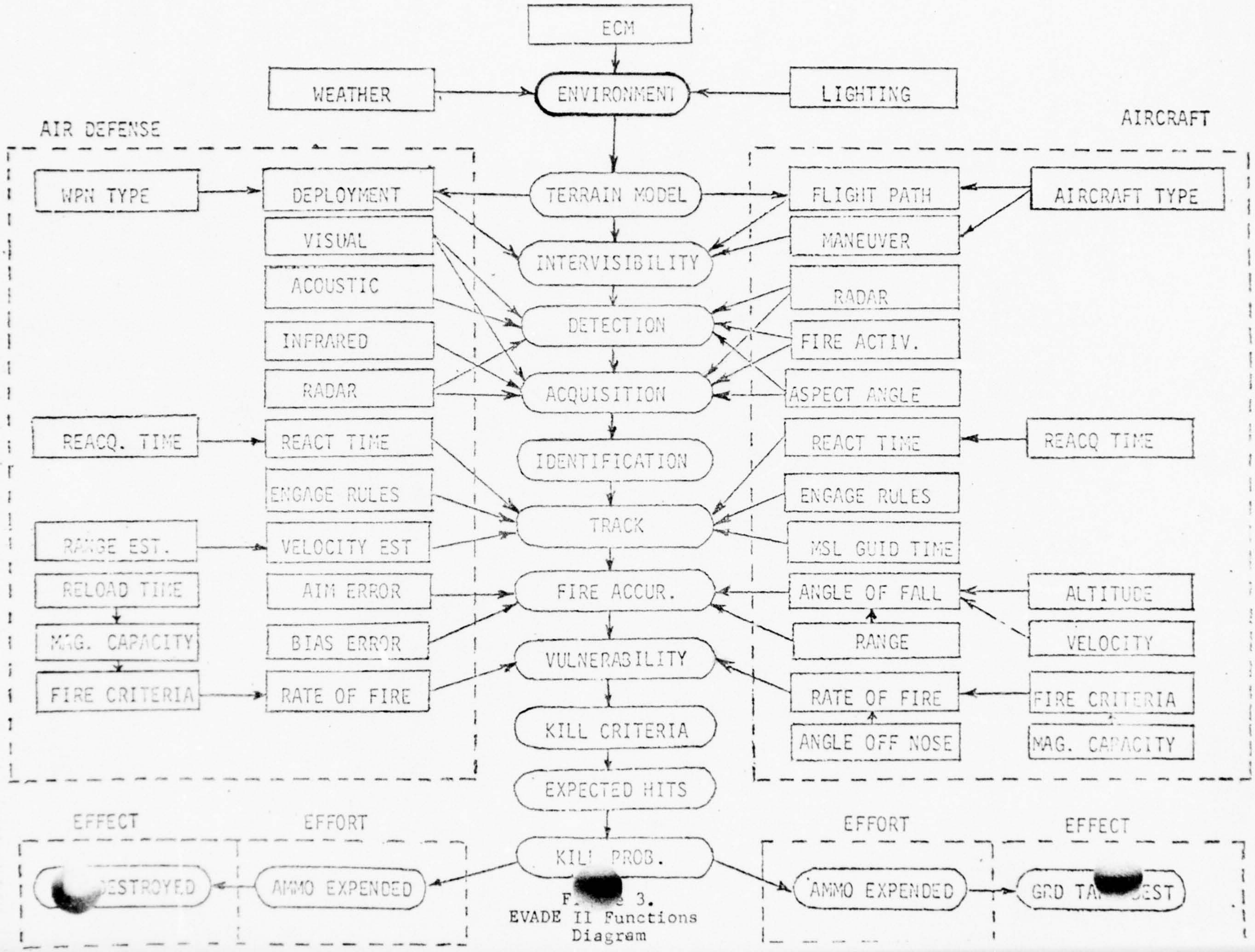
Figure 3 illustrates the interactions of the various functions considered in the EVADE II model. Figure 4 presents the functional structure of the engagement program. The program logic consists of a gun loop, an aircraft loop, and a time loop.

The engagement monitor increments the simulated time, selects the next aircraft, and then proceeds to evaluate all ground weapons against this aircraft for detection, acquisition, firing decision, tracking, and firing. After all ground weapons have been processed for a particular aircraft the next aircraft is selected and the cycle is repeated until all aircraft have been processed. After all aircraft have been processed simulated time is incremented and the above procedures are repeated until one of the termination criteria is met. Attrition of targets and response to fire occur after appropriate delays for time of flight and reaction within the aircraft and time loops.

GLOBAL

GLOBAL is divided into three programs, only one of which resides in core at a time. An executive program also resides in core and is used to call the three programs to execute the simulation. Figure 5 shows the structure of GLOBAL. The first program is an initialization routine to implement various word packing and unpacking techniques for the sake of computer core storage efficiency. The second program reads and stores the input data. It also contains extensive error checking routines. The third program executes the battle simulation and provides a time-sequenced history of events and other significant data. The program logic consists of five major submodels: Detection, Selection, Fire Mission, Damage Assessment, and Game Update.

The GLOBAL engagement program increments the simulated time, determines the intervisibility and detection status of all units, and evaluates whether a mission will be scrubbed. It then processes each unit on both sides through the Target Selection, Fire Mission, and Damage Assessment submodels. After all units have been processed through the weapons interaction submodels, all units are moved, if applicable, their suppression and other status adjustments are made, and artillery kills are assessed. The above procedures are repeated until one of the termination criteria is met.



F[illegible] 3.
EVADE II Functions
Diagram

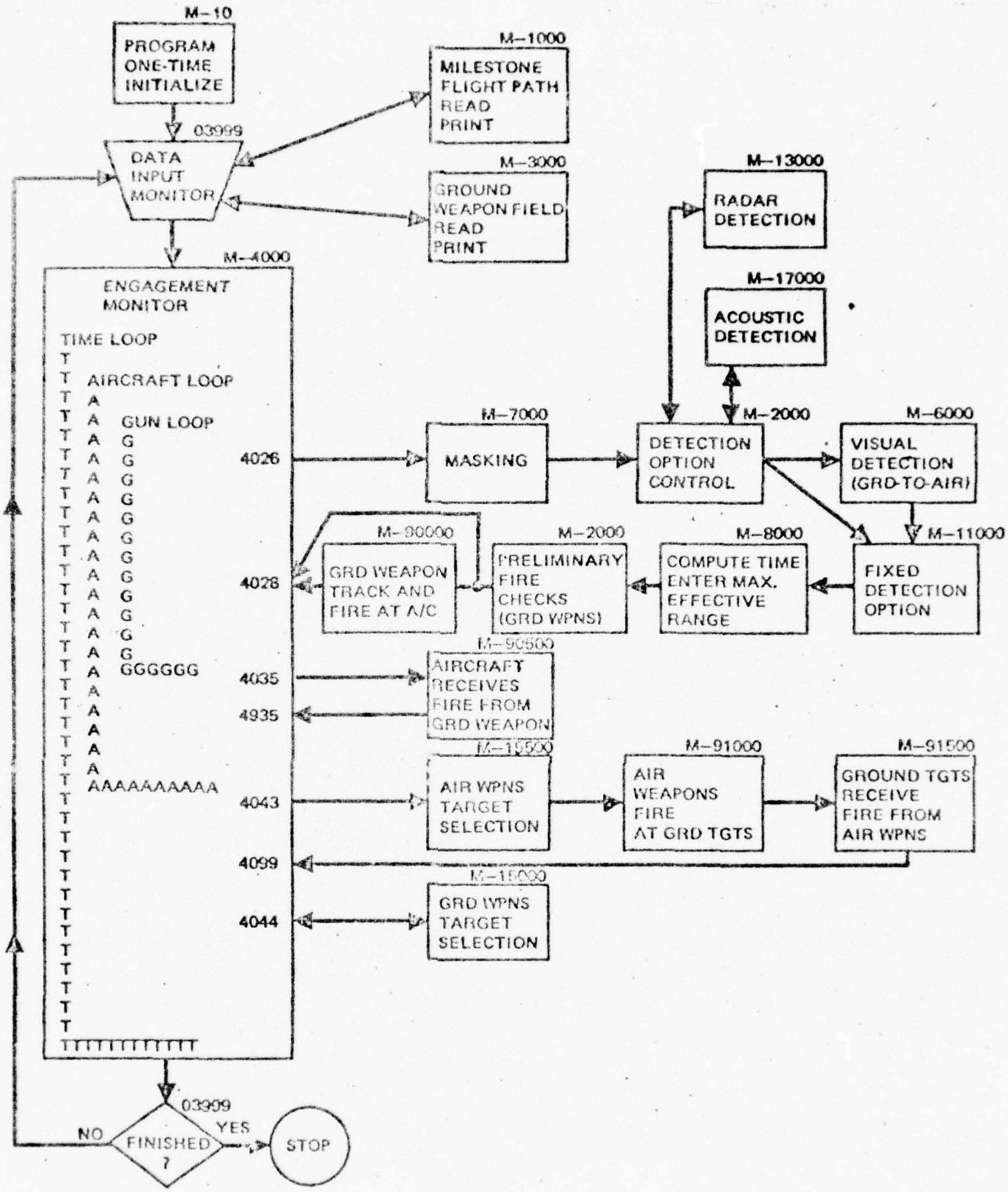


Figure 4. EVADE II Main Program Structure

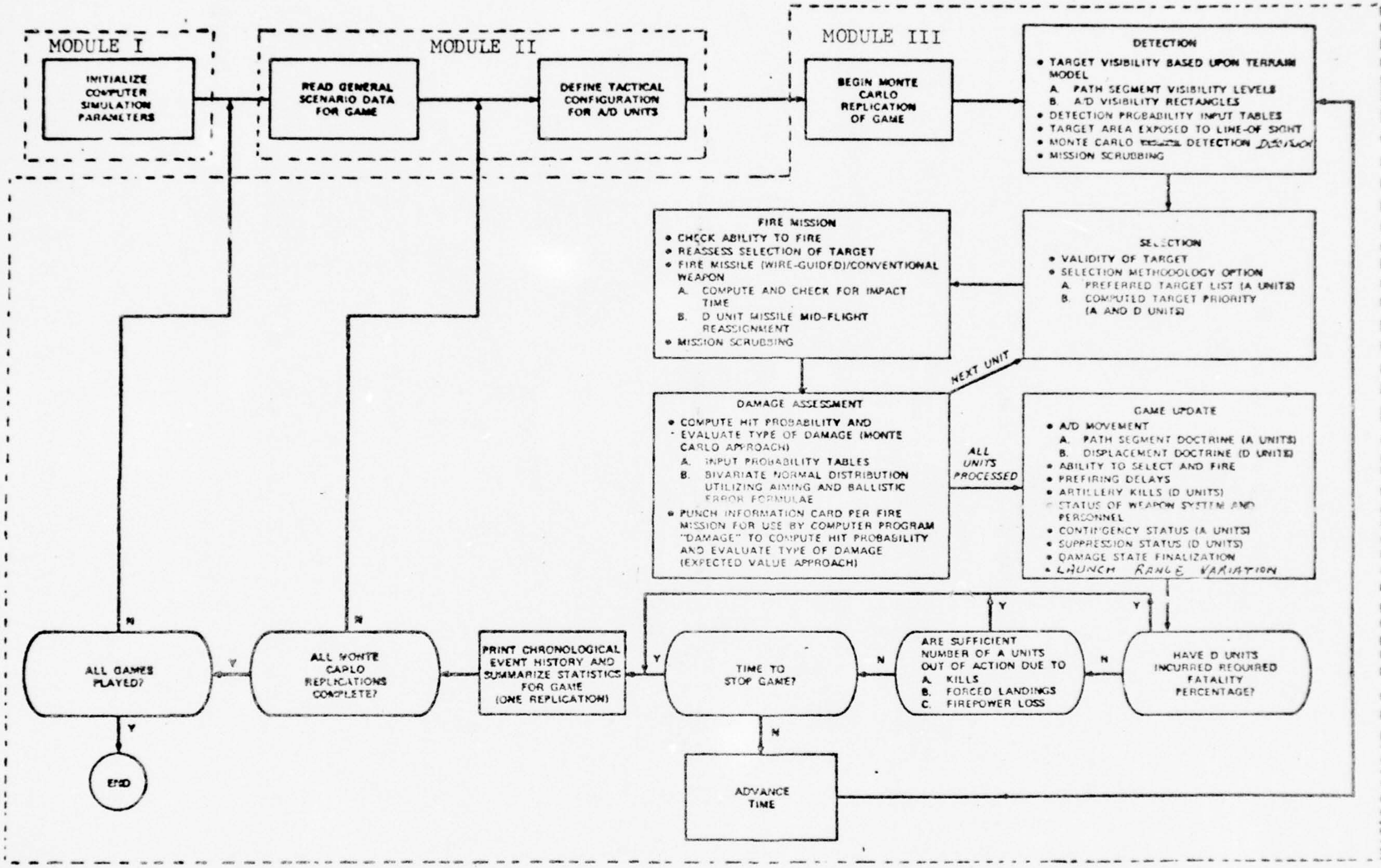


Figure 5. GLOBAL Program Structure

STORAGE

Techniques utilized by each model for the storage of data in the computer are presented in this section. Unique and machine dependent characteristics are discussed.

STORAGE

CARMONETTE

The storage of data in CARMONETTE provides for very efficient use of core. The model currently runs on CDC 6000 series computers and is written in the FORTRAN IV computer language. It consists of five basic logic sections, each section containing several subroutines. Some of the subroutines are common to more than one logic section. In order to minimize computer core requirements, the routines are linked in an overlay, thus allowing certain routines to reside in core only as required. Under these conditions, approximately 165,000 words of core are required to run the Battle Model. Of this total, approximately 9,000 words are reserved for data which reside in core throughout the execution of the program. Any information state which can be represented as "true" or "false," is represented by the setting of a single bit of core. Conditions, such as probabilities, which are representable as a discrete value from zero to 63 are often maintained within one octal byte (6 bits). Probabilities from 0 to 99 are stored in a 6 bit storage area by applying the following rule

$$\text{stored value} = \left[\text{original value} \times \frac{64}{100}\right]$$

where the brackets signify the integer portion of the calculation. The table below presents the stored probabilities for representative original probabilities. As can be seen there are losses of accuracy in use of such a system.

Original Probability	Stored Value
00	00
01	00
02	01
03	01
04	02
05	03
06	03

Original Probability	Stored Value
07	04
08	04
09	05
10	06
20	12
30	19
40	25
50	32
60	38
70	44
80	51
90	57
95	60
96	61
97	62
98	62
99	63

To access these and other such values, service routines were written in CDC assembly larguage (COMPASS).

Although the storage and access of data are streamlined, the transfer of the model to a different computer system would be difficult. The data packing is highly machine dependent, using all 60 bits found in a CDC 6000 series computer, and would require an extensive redesign of the data storage to use a different computer. The packing technique used in CARMONETTE is satisfactorily documented in the Research Analysis Corporation report, "Equal Cost Firepower Study II (ECF-II)," (Vol 1) Annex B3 to Appendix B.

EVADE

Two of the primary determining factors for memory requirements are the maximum number of independent flight paths the program must consider (MFPN) and the maximum number of distinct ground weapon sites that will be used (MAWPN). Up to 20 simultaneous independent

flight path tracks against up to 50 individual ground weapon sites can be simulated. More than one aircraft can be played on a given track. More than one gun tube or missile launcher can be located at one ground position.

These two limits determine the size requirements of 12 large arrays. Each of these arrays requires a total of (MFPN) x (MAWPN) words of memory.

The largest single array in the program is Z (for storing future events, past events, and large data tables) which contains 25,990 words of memory. This can be reduced to 12,000 if necessary. However, the smaller the space allocated to Z, the more care and time that must be taken in the preparation of the flight path data. The data packing techniques used make conversion to other computers difficult. In spite of this difficulty, conversions have been made to CDC 6400/6600 and IBM 360 equipment.

EVADE II runs on the Ballistic Research Laboratory Electronic Scientific Computer (BRLESC) and is written in BRLESC 2 FORTRAN (FORTRAN IV modified). Partial test runs of the model are currently being performed on an IBM 360 and a CDC 6600. EVADE II requires 81,000 words of computer memory, with each word having at least 50 binary bits. The indexing schemes used for the large number of subscripted variables are closely tied to the storage and word packing schemes employed. Use is made of the large BRLESC computer word of 68 binary bits. The indexing schemes have to be extensively modified to allow EVADE II to fit into even a reasonably large computer. Thus, conversion from the BRLESC to another computer is somewhat difficult. It may be possible to adapt EVADE II to computers that use a smaller word size by declaring the Z array to be double precision.

The packing technique used in EVADE II is satisfactorily documented in Evaluation of Air Defense Effectiveness (EVADE II) Digital Simulation for Aircraft Survivability, draft, September 1972.

GLOBAL

The highly efficient storage of data in GLOBAL is achieved by data packing. All input data are maintained in core in a packed mode. Over 50% of the 8,000 executable program statements of GLOBAL address data packing and unpacking. The major problem presented in this

particular packing is the lack of consistency. Several elements of different sized data are merged together and stored under the same name, making the program extremely difficult to analyze or alter. Also, because the data packing techniques utilized in GLOBAL are specifically designed for a Control Data Corporation machine, conversion of GLOBAL would be difficult, requiring almost complete reprograming.

The packing techniques used in GLOBAL are not documented. Therefore, the following examples are presented as part of this report.

-- Masking variables to select certain contiguous bits --

Description --

These variables are identified by the letter M followed by four numbers. Only the right-most 48 bits are considered in any of these masking operations and the four numbers of the masking variable name identify which of these 48 bits will be masked out (selected) and which will not.

The first two numbers identify where the masking will start (the left-most bit of the 48 bits is considered bit number 0) and the second two numbers are the numbers of bits to be selected.

Example --

Variable	Description	Octal Configuration
M0112	Selects bits 1 through 12	377740-10 zeros - B

-- Masking variables to delete certain contiguous bits --

Description --

These variables are identified by the letter NM followed by four numbers. Only the right-most 48 bits are considered in any of these masking operations and the four numbers of the masking variable name identify which of the bits will not be masked out (deleted).

The first two numbers identify where the bit deletion will start (the left bit of the 48 bits is considered bit number 0), and the second two are the number of bits to be deleted.

Example --

Variable	Description	Octal Configuration
NM0112	Deletes bits 1 through 12	Not M0112

-- Shifting variables --

Description --

The first two characters of the variable name (ML or MR) indicates a left shifting or right shifting variable. The right two characters determine the number of bits to be shifted.

Each variable is loaded left justified with a four character octal number. This variable will be attached as an exponent to the variable to be shifted. It is thus biased by 2,000 for left shift variables and by 1,777 for right shift variables. Remove the bias by subtracting the biased exponent from the bias. The decimal equivalent of the unbiased exponent tells you the number of bits to the left (for a positive number) or right (for a negative number) to move the binary point to obtain the true binary value of the coefficient.

Example --

Name	Description	Octal Configuration
ML 12	Move left 12 bits	2014-16 zeros - B

Bias	Biased Exponent	Shift Value
2,000 -	2,014 $= -14_8 =$	-12_{10}

Usage --

Shift the integer variable IVAL left 12 bits

X = IVAL . OR . ML12

IVAL = IFIX (X)

-- Masks to select certain continguous bits and right justify --

Description --

The first two characters of the variable name "MS" identify this type of variable. Again only the right 48 bits of the variable to be shifted are considered and the four numbers of the masking variable name identify which bits will be selected and right justified.

The first two numbers identify where the selection will start (the left bit of the 48 bits is considered bit number zero), and the second two numbers are the numbers to be shifted.

Example --

Name	Description	Octal Configuration
MS0101	Shift one bit starting at bit number 1	17212 - 15 zeros - B

Bias		Biased Exponent				Shift Value
1,777	-	1,721	=	56_8	=	46_{10}

Right justify the second bit of the integer variable IVAL.

X = IVAL. .MS0101

IVAL = IFIX (X)

The GLOBAL model is currently maintained on a CDC 6400 series computer system, with 65,000 words of core storage and approximately 65,000 additional words stored on auxiliary disk. The simulation is written in FORTRAN IV.

COMMENTS ON STORAGE

All three models use some form of data packing. Though packing information into all available word space gains economy of storage, it limits the flexibility of the model. It requires additional computer time to pack and unpack these values; however, the time required to retrieve data from peripheral devices is large compared to the time required to unpack data stored in core memory.

SEQUENCING SCHEME

A computer simulation of combat must contain a method for sequentially processing the myriad individual actions and events which make up the total battle picture. "Event-sequencing" and "Time-sequencing" are names given to two common methods for allowing the simulation of progress in a logical manner. Which method is used and the details of that method are explained here for each model reviewed.

SEQUENCING SCHEME

CARMONETTE

CARMONETTE is event-sequenced as distinguished from time-sequenced. This means that the processing sequence (i.e., the order which submodels are exercised) depends on events rather than the passage of an arbitrary time period. An event is the termination of an activity and it in turn defines the potential initiation of an activity or activities by all units affected. For example, an event can be the termination of the time of flight (i.e., impact). At this point all units in the target area are assessed. They each may respond, depending on their type, in different ways. The time to accomplish the response is predicted and the current time plus the event time is established as a future event for each responding unit. The time required for the activity of damage assessment by the firing unit likewise will define a future event for that unit (e.g., update the unit's intelligence to indicate that the target is now dead). CARMONETTE activities have been divided into very short subactivities. For example, the activity of weapons employment has been divided into aim (or reaim) time, reload time, time of flight, and damage assessment for each weapon type assigned to a unit. In a lower resolution simulation the activity of weapons employment may aggregate all the above subactivities of an entire unit into a single activity. In an event-sequenced model there is no need to examine the time interval between events or query all of the units to see if they are doing anything. A model on a digital computer cannot use truly continuous time values; the smallest time resolution possible in CARMONETTE is 1/4096 minute $(1/(2)^{12})$.

There are three general types of activity which occur in the model: unit operations (mount, end mount, dismount, end dismount, vertical altitude change, move, boundary crossing, surveillance, communication), weapon activities (target selection, loading, aim, end aim, firing, impact, assessment), and tactics (out of ammunition, mission change). The events for each of these activities are maintained by the use of twelve clocks and twelve event code registers for each unit.

The game is controlled by scanning all units' clocks to find the minimum time (greater than or equal to the current time). The activity associated with that clock is selected as the simulation activity. These values are maintained in game control cells KTIME and KCODE. Additionally, the array JATRIB contains the current attributes of each unit, and array JUCHAR contains the current and original descriptions for the units. Other arrays used to control the simulation are described in the documents "CARMONETTE IV and CARMONETTE V," Coordination Draft, 11 November 1971 (RAC).

EVADE

EVADE II is time-sequenced, using a fixed time increment which is given in the input. The model runs by processing these time increments, one after the other, and examining all of the units in turn. If a unit is in motion, it is advanced a distance along its path which is appropriate to the time increment. If a unit is selecting a target or firing, the time increment is divided into smaller steps to take account of the short times associated with human reaction, projectile time-of-flight, etc. The order of processing the units, within a time increment, is fixed by the input; this can produce bias when two units have interacting activities within a single time increment.

For the aircraft weapons, the time-dependent sequence of events of each engagement is the following: The pilot notes the receipt of fire or detects a ground target, his reaction time elapses, he fires his weapon, time-of-flight elapses, and attrition accumulates until the engagement is terminated.

For the ground weapons, the events are these: target detection (visual, acoustic, infrared, or radar), acquisition, unmasking, elapsing of weapon system reaction time, target moving into maximum effective range, projectile or missile time-of-flight, arrival at the first intercept point, and subsequent accumulation of attrition or probability of kill. This process continues until the target becomes masked, goes into a dead zone, is suppressed, is killed, runs out of ammunition, or goes out of range.

The model is sensitive to the length of the time step chosen.

GLOBAL

Module III of GLOBAL executes the battle simulation by time-sequencing, similar to EVADE, and provides a time-sequenced history of the major battle events together with summary tables and statistical measures for assessing the outcome of the simulation. The simulation of the battle sequence of events is performed by sequentially processing the five major submodels: detection, selection, fire mission, damage assessment, and game update. Coordination of movement related to attacking units is implemented via the use of visibility or exposure levels, e.g., if a coordinated helicopter is desired, zero exposure levels will be given at a hover mode of operation until an attack is ready to be carried out.

Weapons status updates are made by the Update subroutine. This subroutine updates the position and status of all game units according to events that have occurred in the current time increment. There is a significant breakdown in GLOBAL's attrition logic, which hinges on the choice of the input increment length. This problem is discussed in detail later in this report under ATTRITION.

INPUT AND OUTPUT

INPUT DATA

The data requirement for each of the models is described in this portion of the report. The specific input formats and the number of items of information for each of the parameters for each model are not discussed. A brief introduction to the data editing or other processing performed by each model is provided. While a distinction is made between the input data discussed here and the submodels discussed later, it is merely for purposes of sequential presentation. Consideration of a submodel cannot be separated from its input data because the model logic assumes a particular view of the world as concerns input data. In addition, some data are required only to permit the bookkeeping function and have no analog in the actual combat situation being simulated. Other data are inherent in real situations, organizations, or operations and, in these cases, are never explicitly defined. For the purpose of a simulation, however, these bookkeeping and inherent data items are required to represent reality. The sensitivity of a model to both the bookkeeping and the inherent data is just as important as its sensitivity to equipment characteristics.

INPUT DATA

CARMONETTE

The initial CARMONETTE run is generated by a card deck which defines the complete scenario. This input deck is processed by the first preprocessor program to create an intermediate data tape. The intermediate data tape is then used as input to the second preprocessor program, which performs an error scan of the input data and produces a final output data tape to be read by the battle model. The battle model also requires certain simulation control data, such as the maximum battle time, number of replications, and other battle termination data. Those data are entered on cards at execution time.

Later CARMONETTE runs may be generated by making changes or additions to a previously created intermediate data tape. The desired changes are processed by the first preprocessor to define the new scenarios.

Additional data are entered on cards to the post processor program in order to produce the desired optional outputs.

The initial CARMONETTE input data consist of a fixed portion and a larger portion which is variable in quantity. The latter depends primarily on the number of units being played, the number of weapons and sensors those units are given, and the unit tactics (orders). The fixed input requirement is essentially a description of the terrain (grid square characteristics). The input parameters required to run the CARMONETTE simulation are summarized below:

WEAPONS CHARACTERISTICS

Weapon type

Range (min, max)

Crew size

Aim time (mean and standard deviation)

Re-aim time (mean and standard deviation)

Load time (mean and standard deviation)

Reload time (mean and standard deviation)

Average velocity of projectile

Artillery impact area size

Orientation of artillery impact area

Firing signature (flash, smoke, dust, etc., for direct fire weapons only)

Ammunition type (2 types per weapon)

Number of rounds per trigger pull

Neutralization weight per round (e.g., 1 for rifle, 5 for mortar)

WEAPON ACCURACY (NONARTILLERY)

For each weapon type three cards are provided. They are the SD at maximum effective range, at .707 maximum effective range, and at zero range for the following situations:

First round (standard deviation) for various target postures and ammunition types

Subsequent round given first round hit

Subsequent round given first round miss

ORDER OF BATTLE

Description of unit (tank, recoilless rifle, etc.)

Main weapon of each unit

Quantity of main weapon type in the unit

Ammunition supply (2 types per weapon type)

Unit's second, third, and fourth weapon types

Number of men in each unit

Number of vehicles in each unit

Number of men that remain with each vehicle when passengers dismount

Size of area occupied by each unit when deployed

Average area presented to a visual observer by the largest element in the unit

Height of unit's sensor device above ground

Designation of troop carrier units

Designation of units unable to move

Designation of units unable to fire (e.g., HQs)

Designation of units in which troops dismount when unit is hit

Designation of units which can call artillery

Designation of units to hold fire until targets are within hold fire range

UNIT DESCRIPTION

Number of Blue and Red units being played

Target class

Vulnerability class

Element-size class

Mobility class

Fire-response class

Sensor class

Sensor height

Maximum men per vehicle

Fraction of time a support unit is not exclusively supporting the simulated force

UNITS KILLABLE AS SINGLE ENTITY

Designation of which units are killable as single entities, e.g., aircraft. (Other units can have as many as 60 killable elements.) [Developers report that this input has been deleted.]

DANGER-STATE TABLE

Designation of serious vulnerability, moderate vulnerability, or invulnerability for each vulnerability class against each target class, in three range intervals

THRESHOLD FOR RESPONSE

Number of rounds required for a unit in each fire response class to be pinned down, proceed with caution, take evasive action, abort firing run mission (aircraft), drop to treetop level if not on firing run

TARGET PRIORITY LIST

Target class priority for each direct fire weapon type

TERRAIN DATA

Elevation (0-4095 feet)

Height of vegetation (0-63 feet)

Cover (16 indexes)

Concealment (16 indexes)

Cross-country trafficability (3 indexes)

Trafficability of roads (4 indexes)

KILL PROBABILITY AND AMMUNITION SELECTION

Preferred ammunition type to be used against each vulnerability index

Kill probabilities of units in each vulnerability class by each ammunition and weapon type

PROBABILITY OF KILLING INFANTRY

Probabilities of killing infantry in various net-cover indexes by weapon and ammunition types

PROBABILITY OF INDICATING DEATH

Estimated probability that a unit will exhibit (smoke, cease fire, stop moving, etc.) its death when killed and the firer will recognize it, recorded for each vulnerability index

LIKELIHOOD OF MOVING

Assessment time

Decision time

Probabilities of a unit moving under various conditions

GROUND MOBILITY

Slope (class thresholds)

Rate in meters per second for each ground mobility index for each slope class

Dismount (mount) time

AIR MOBILITY

Air mobility class

Descent time

Climb time

Maximum altitude

Altitude change thresholds (degrees)

Dismount time

Movement rates

Altitude above ground (contour flying)

Level flight altitude

ORDERED MOVEMENT RATES

Movement rates for ground and aircraft units (7 each)

Attack speed index for aircraft

DETECTION

Probability of loss of target information

Scan interval

Solid angle threshold

Minimum sensor range

Minimum target solid angle at sensor

Probability of not detecting a target

Probability of detecting but not pinpointing a target

Probability of detecting and pinpointing a target

Probability that a target is still pinpointed

Probability that a target which has been pinpointed is lost

Probability that a detected target is lost

Probability of detecting that a target is dead

Probability of erroneously pinpointing an unknown target that has fired

Probability of pinpointing an erroneously pinpointed target after it has fired

Image intensifier data

Background reflectance

Target reflectance

Visible light scattering and absorption coefficients

Radar degradation factors

Radar performance factors

ORDERS

Type of fire

Movement doctrine

Change in altitude

Rate of movement

Target priorities

Number of rounds to be fired

Location of targets

Location of all units

Time of battle

Intervals of time of events

Order to stay at present status (when applicable)

Order to skip forward or backward a specific number of orders (when applicable)

First order number

Actions when a unit runs out of ammunition

Location of escape points

COMMAND, CONTROL AND SURVEILLANCE CHARACTERISTICS

Unit number

Superior headquarters designation

Subordinate CCS units

Subordinate weapons units

Buddy unit designation

Sensor type, class, height

Length of communications cycle

Comments on CARMONETTE input data follow:

Those data points defining the mean and standard deviation for various populations are input without distinction to the shape, or density function, of the distribution. The implication of a normal distribution for each such population is thus noted. Also, much of the input data is dependent upon other input parameters. For example, detection probability is dependent on scan time; aircraft descent and climb times are dependent on standard altitude increment chosen; etc.

Reference WEAPONS CHARACTERISTICS, minimum number of men required to serve each weapon: There is no input to specify a reduced effectiveness of crew-served weapons when crew losses are sustained (e.g., longer load time, aim time, etc.).

Reference WEAPONS CHARACTERISTICS, relative neutralization weight: The concept is sound, provided there is a credible basis for the determination of these values.

Reference ORDER OF BATTLE, average area presented to visual observer by the largest element in the unit: One could better simulate reality by varying the area with the view aspect (front, side, or top).

Reference UNIT DESCRIPTION, maximum men per vehicle: The rationale behind the statement in the documentation, "If the survivors cannot be accommodated in the remaining vehicles, all troops will dismount and proceed as a dismounted unit," is open to debate.

Reference THRESHOLD FOR RESPONSE: The term "caution" on form number 7 is a carryover from an earlier version and is no longer functional.

Reference TERRAIN DATA: If two roads with the same trafficability exist in adjacent grids, a "phantom" road will be simulated. To eliminate this possibility, other than by moving the road, it might be desirable to assign road numbers.

Reference KILL PROBABILITY AND AMMUNITION SELECTION: The origin of these data is not specified. Documentation should include the source.

Reference PROBABILITY OF KILLING INFANTRY: The probability of killing infantry is equivalent to the lethal area divided by the total impact area. For nonartillery fragmentation rounds the impact area is the area of one grid square. The impact routine uses these probabilities, given a target was in the impact area, to assess the number of kills. The probability assessment is highly sensitive to the grid size employed. For artillery, the impact area width and length are recorded in meters. Those values are constrained to be 1 x 1, 1 x 3, 3 x 1, or 3 x 3 grid squares. The lethal area is a fixed quantity for a given weapon/ammunition selection. Thus, if these probabilities are to be accurately measured, the impact area designated must be carefully considered in view of the grid size selected. It may be desirable to permit additional impact area classifications.

Reference PROBABILITY OF INDICATING DEATH: It is not clear why all elements of a unit, though having the same vulnerability index, would have the same probability of indicating death.

Reference AIR MOBILITY: Provision for emplacment time has not been made.

Reference DETECTION: The simulation is more accurate for small scan times.

Reference DETECTION: It may be worthwhile to provide additional solid angle thresholds in order to gain model resolution.

Reference DETECTION: The probability assessments are directly linked to the scan time. Aside from this sensitivity, there may be an effect on the number of targets detected during the interval.

EVADE

Operation of the EVADE II program requires input data generated by the MASKPAS computer programs. MASKPAS consists of a set of four BRLESC II computer programs: Weapon Site Heights, Flight Path Generator, Terrain Following, and Intervisibility. These four programs are executed sequentially to generate a three-dimensional aircraft profile and the mask history between the aircraft and up to 50 independent ground weapon sites. Terrain data and flight path data are recorded on tape while all other input to MASKPAS is on cards.

The input to the remainder of EVADE II, the attrition program, consists entirely of punched card data. Two basic types of data are provided to the program for each engagement, instruction-coded data and Z-list flight path data. The instruction-coded input data are separated by coded header cards which indicate the data type to follow. In runs consisting of several engagements, this allows the data for prior engagements to be supplied to subsequent engagements by reading only those data which are changed from the previous engagement. The Z-list flight path data, a detailed time history of the aircraft flight path, velocity, and masking status, is generated by the MASKPAS program.

The input parameters required to run EVADE II are summarized below:

WEAPON SITE HEIGHTS PROGRAM (MASKPAS)

Number of weapon sites

Grid coordinates of each weapon site

Height of each weapon above ground

FLIGHT PATH TRACK GENERATOR (MASKPAS)

Number of mission milestones

Range interval between intermediate points along the mission trajectory

Grid coordinates of mission milestones

TERRAIN FOLLOWING (MASKPAS)

Option for nap-of-the-earth (NOE) flight

Constant altitude of flight (not NOE)

Number of terrain altitude vs mission range data points

Terrain altitude for all data points

Aircraft range for all data points

Number of velocity data points

Aircraft velocity at all data points

Number of aircraft altitude data points

Aircraft reference height above terrain

Trajectory restart range

Trajectory restart time

Trajectory restart grid coordinates

INTERVISIBILITY (MASKPAS)

Nap-of-the-earth option

Constant altitude option

Constant altitude (if applicable)

Constant velocity (if applicable)

Starting flight path trajectory point

Ending flight path trajectory point

Number of weapon sites per flight segment

Number of each weapon site considered

AIRCRAFT

Number of airborne weapons

Flight path number of each weapon

Weapon type

Weapons locations

Ammunition available

Aircraft type

Single round probability of kill

Vulnerable area interpolation for each vulnerable component on aircraft

Grid coordinate locations of aircraft

Number of milestones in flight path

Time increment used to advance elapsed time

Initial number of aircraft on flight path

Aircraft velocity

Orientation of the aircraft with respect to velocity vector

Flight path altitudes

Flight path wave option

Flight path offset constants

Probability of aircraft kill

Probability of forced landing

Maximum aircraft velocity

Meteorological range

Glimpse time

Probability of detection

Vulnerable area aspects

Aircraft projected area

Half length of the aircraft

Maximum turning capability

Reflectivity coefficients

Troops carried by flight path

Time required to unload troops

Vulnerable area parameters

Range to target

Azimuth angle to target

Dispersion error

Bias error

Air weapon elevation limits

Weapon engagement rules

Rates of fire

Time between bursts

Number of rounds per burst

Target desirability factors

Projectile angle of fall

Projectile terminal velocity

Projectile time of flight

Relative altitude of weapon to target

Superelevation

GROUND WEAPONS

Accuracy coefficients

Audio detection ranges

Eye acuity data

Fire boundary limitations

Weapon type

Target closing velocity

Range to target

Rate of fire

Time between bursts

Number of rounds per burst

Mask angles

Total number of distinct ground weapons

Grid coordinate locations of weapons

Ammunition type

Initial flight path selected for engagement

Initial azimuth setting

Gunner estimation errors

Slant range to lock-on boundary

Engagement methodology options

Radar detection ranges

Radar elevation angles

Visual acuity versus liminal contrast

Air ammunition used against ground weapon

Projectile angle of fall

Projectile striking velocity

Weapon vulnerable areas

Maximum effective range

Reaction time

Muzzle velocity

Ballistic coefficient

Ammunition available in loaded magazines

Reload time

Level gun mount elevation limits

Azimuth slew rate

Settling time

Reacquisition time

Total ammunition available

Level of P(k) for suppression

Level of P(k) for destruction

Time required for suppressed ground weapon to regain status

Closest engagement range

Target priority rules

Gun barrel elevation angle

Projectile time of flight

Projectile height

Projectile elevation angle

Comments on EVADE input data follow:

As do most models its size, EVADE II requires considerable input data. Existing input routines perform very limited editing of input data by checking the bounds of selected variables. The input routines terminate processing upon detection of the first erroneous datum rather than processing the entire data base and flagging errors. The procedure could significantly lengthen data base set-up time, especially for a new user. It would appear to be a better tactic to review the entire data base, flagging erroneous data, on each pass through editing routines.

GLOBAL

GLOBAL utilized stochastic Monte Carlo techniques for most evaluations, with the exceptions of movement, visibility, and selection. Data preparation has just recently been automated to some extent. Peripheral programs now exist in the form of aircraft flight path generators and procedures for determining line-of-sight from digitized terrain. The efficiency of these recent modifications was not evaluated for this report.

The input parameters required to run the GLOBAL simulation are summarized below:

GAME PARAMETERS

Number of replications

Time limit

Seconds per time interval

Meters per grid interval

Attrition percentage to end game

Mission scrub rules

Visibility -- designate whether visibility will be given by path segment or by rectangular areas of the battlefield

Random number generator starting point

Piece-wise linear distribution function of navigation errors

Range intervals

DEFENDER UNIT PARAMETERS

Grid coordinate location

Number of weapons

Weapons types

Target type

Priority as a target

Angular boundaries of firing sectors (absolute and preferred)

Option displace

Probabilities of displacing

Time to move and be available as a target

Time to move and be able to fire

Probability of being killed by artillery while moving

Crew served weapon designation

Number in crew

Crew recovery delay -- time to fire again if one member is killed

Time interval in which the unit will be killed by artillery

Whether or not unit can be suppressed

ATTACKER UNIT PARAMETERS

Starting grid coordinates

Initial heading angle

Number of weapons

Weapon types

Target type

Priority as a target

Angular boundaries of firing sectors (absolute and preferred)

Whether aircraft or ground vehicle

Whether or not stop is contingent upon detecting a target

Length of stop

Time between stops

Whether or not move from stopped point is contingent upon completing quota of fire missions

Fire mission quota

Whether or not unit is the member of a team (units in a team move together)

Number of riders (passengers)

Unit type

Team size

Team position

Whether or not primary weapon can be fired while moving

Number of sub-units

PATH SEGMENTS

Altitude

Maneuver error

Velocity

Duration -- number of time intervals

Visibility state

Exposure level to each defender unit

Move -- number of X increments and Y increments in each time interval

Time to escape when scrubbing a mission

Pitch angles

Roll angles

Trigger navigation error decision and move to adjusted location signal points

Correct navigation error and return to original path signal points

Synchronization of movement with other attacker units signal points

X, Y coordinates defining rectangular visibility areas

Exposure level

Defender units which have intervisibility with each path segment

Target list of defender units in order of priority

Path segment sequence number

WEAPON PARAMETERS

Minimum and maximum firing ranges

Number of rounds in a burst

Delay between bursts

Number of bursts before reloading

Reload delay

Probabilities of detecting a target before it has fired

Piece-wise linear distribution function of acquisition delays

Appropriate target types

Projectile flight times by range

Impact velocities by range

Damage option

Whether missile is wire-guided

Exposure levels where firing is permitted

Firing rate option

Minimum missile switching time

Vulnerable areas if firer is using damage options 1, 2, 3

Total presented area

Percent of total area vulnerable to kill

Percent of total area vulnerable to suppression

Damage probabilities if using option O (zero)

Probabilities of being killed

Probabilities that a near miss will cause a suppression

Fire moving and/or stopped

Delay to fire after coming to a stop or starting to move

Whether a massive weapon type (crew served, totally killable by one fire mission)

Whether the weapon can cause suppression

Probability of being damaged

Probability of forced landing or mission kill if aircraft

Probability of loss of mobility or loss of fire power if ground vehicle

Rider weapon type

Rider firing sector angular boundaries

Comments on GLOBAL input data follow:

In many computer models the logic used in processing far outstrips the complexity of the inputs. This is not the case in GLOBAL. Pregame

data preparation is extensive and complex for this model, especially in preparation of attacker path segments and the subjective visibility or exposure levels.

GLOBAL users must input many of the variables CARMONETTE and/or EVADE calculate. This is especially true where weapon parameters are concerned. In some studies it may be advantageous to precalculate some of the input in order to more effectively evaluate the sensitivity of certain parameters. Thus mention of the extensive pregame activity in GLOBAL is not to be construed as a criticism.

OUTPUT

This section gives a description of the resulting computer output of each simulation run.

OUTPUT

CARMONETTE

Two files are produced which contain selected data obtained during the battle simulation. One file contains a history of significant events that occurred. The other file contains a time series of samples of unit information, position, and strength. These files are processed to produce edited output as requested via the input cards provided by the user. Some of the obtainable outputs are:

Event history messages containing the time, location, and nature of unit events.

Ammunition expenditure report.

Kills recorded by weapon type, side, and target class broken down by vehicles and men.

Total moves, firing, rounds received, initial and final men and vehicles, time of death of unit, and initial and final ammunition supplies of each unit.

Summary of frequency of engagement ranges.

The treatment number, replication number, date of the run, computer time used, the last random number, the reason for termination of the battle, and the battle time at termination are reported for all runs.

EVADE

The output resulting from execution of the model is divided into four areas: flight path history, weapon site history, weapon site history, summary history of the total engagement, and visual detection model calculations. Control of these four categories of output is accomplished through exercise of the print control options. Using the print control options, the various categories of output can be directed to any desired output device or suppressed entirely. The output available is as follows:

The flight path history details the events which occur along each segment of the flight path, relative to each gun site. Such information as weapon type, ammunition expended, mask status, range between weapons, when firing takes place, closing velocity, flight path P(k), when aircraft is killed, distance flown, cumulative probability of kill of aircraft.

The weapon site event history consists of the time history, for each ground weapon site, of the major events in the engagement, such as detection of the aircraft, mask status, when aircraft is in or out of effective range, when the ground site fires or receives fire, a continuous record of flight path and ground weapon P(k)s, and indication of when the ground weapon is suppressed or destroyed.

The total engagement history includes a summary of P(k) level of each flight path, weapon assignments, count of surviving aircraft, and indications of whether ground weapon sites have been suppressed or destroyed.

The visual detection calculations output option has not been implemented.

In addition, the program generates printed output continuously during the processing of the engagement as an aid in tracing the progress of the computations. It also generates messages to the user concerning particular events as the engagement progresses.

GLOBAL

The user determines which events in the history of each run will be printed and which are to be put on tape for off-line card punching. The printed events are in chronological order except for kills. Kills are saved until the play ends in order to divide the credit among the firers whenever there are simultaneous kills. The events depict when:

Fire mission is a total miss

Suppression is caused by a near miss

Result of fire mission is total kill

Result of fire mission is a killed crew member

Kill of artillery

Visibility exists between combatants

Acquisition delay ends

Target is selected

Missile cannot complete its flight

Move is made

Ammunition is exhausted

Target is detected

Firing is initiated

Each event which is printed is described by a line of output giving firer's name, firer's weapon type, event, target number, target's weapon type, current time interval, target grid coordinate location, firer's grid coordinate location, and range.

At the end of each play a summary of the event history is printed to include the last random number generated by the program, number of the run, number of time intervals played before ending, and computer time used.

The next section of output gives the kills and the average killed in all the prior plays of the game with standard deviations.

Three groups of shot tallies follow. The first gives the shots fired by primary weapons, the second gives the shots fired by secondary weapons, and the third gives the shots fired by riders (passengers) weapons.

An output tape containing card images can be used on an off-line punch to produce cards or can be used as input to a separate program.

EVENT GENERATION SUBMODELS

The detailed discussion of the submodels covers the event generation and the interaction assessment processes. It is difficult to separate the submodels into these classifications because, for example, the assessment of an impact on a target often generates new events of target reaction (i.e., suppression, target selection for return fire, calls for supporting fire, etc.). In this portion of the report on event generation the following submodels will be discussed: route selection, line-of-sight, target acquisition, target tracking, firing decision, and target suppression/response.

ROUTE SELECTION

Route selection is defined as the process by which the model moves its units over the playing area. The manner in which the playing space of the model simulates the actual battlefield is involved (area, resolution, topography, vegetation, trafficability, etc.) as well as the logic employed in making the moves. CARMONETTE uses dynamic route selection in which the moves are determined by input rules, whereas EVADE and GLOBAL use preprogramed routing in which the entire paths are input.

ROUTE SELECTION

CARMONETTE

CARMONETTE considers unit movement within a network of grid squares (63 x 63). The square size is optional, from 10 meters upward. A unit's movement is governed by a set of user defined orders, and by other criteria implicit in the model logic. Generally, these will provide for conditional movements based upon the unit's assessment of battle conditions, hostile fire, the unit's mission, concealment, terrain, etc.

Each unit must be directed to move, stay, or fire by means of a preprogramed set of instructions. There are three fundamental types of orders: move, stay, and skip. Fire orders are combined with the move and stay orders.

Movement: A unit may be ordered to move without stopping or to move according to a doctrine to a designated grid square. The doctrine permits the unit to stop with a specified probability depending on available cover and available targets.

For purposes of classifying these movement doctrines, four tactical situations are considered, and a probability of moving is provided for each situation. These tactical situations correspond to the times a unit has:

No cover, with no target for its main weapon.

No cover, with a target for its main weapon.

Cover, with no target for its main weapon.

Cover, with a target for its main weapon.

A unit is assigned a probability of moving according to its mobility class and ordered doctrine. Different doctrines can be assigned to each force. Each mobility class on each side may be assigned as

many as four different doctrines. For example, a different movement doctrine may be assigned for each mobility class and each side during each of four different phases of the battle.

Aircraft and ground units may be ordered to travel at a particular rate during the battle. The order specifies which rate will be used in each situation. When a unit selects a move, it will do so at its ordered rate if it is physically possible. Units can also be ordered to move at the maximum rate for the terrain conditions.

In those situations when a unit is out of ammunition or being suppressed by indirect fire, it will travel as fast as physically possible. When a ground unit is receiving hostile direct suppressive fire, it will automatically travel at the slowest rate for its mobility class.

Each of the types of aircraft is assigned an attack speed index that specifies the ordered movement rate the aircraft should use when executing a firing run toward a target.

Stay Commands: A unit may be ordered to stay at a location for a period of time, or until a certain time, or until it fires a prescribed number of rounds using its main weapon.

Skip Commands: Skip commands enable units to go back and repeat sequences of orders under specified conditions or advance over sequences to a desired sequence. When executed, these skip orders create the flow of control through the entire set of instructions for each of the units in the battle. Complex tactical maneuvers can be simulated using skip commands and sequences of orders.

When a unit expends all its ammunition for its main weapon, it can react in one of three ways: it can continue on its mission, it can halt and fire its other weapons, or it can withdraw immediately to an escape point. One skip order is conditional on a friendly unit's arriving in a certain square.

Helicopter units may be given any type of order that a ground unit may be given, except than an altitude index must be included in its set of orders. In the following discussion, emphasis will be given to those program statements which are relevant to aircraft movement.

The major routine that simulates the decision of whether or not a unit should move is called MOVE. It determines the next grid square, computes the altitude change that is to be simulated and the horizontal moving times for completion of that move, and generates firing run orders. This routine calls several subroutines.

The route selected when the unit is not oriented diagonally with the objective grid square is not the shortest route. Considering the unit's present and objective grid squares to define the extreme corners of a rectangular box with sides parallel to the grid axes, the direction of movement is along the longer side of the box. This continues until the rectangular box becomes square, at which point the further movement is diagonal. A program change to select a more direct route is considered appropriate and feasible by the model developer. [The developers state that a recent change now provides for a more direct route. This change was made after the model was examined for this report.]

The MOVE routine determines the time required for the unit to move from its current location at the center of the grid to its next location at the boundary of the grid. For aircraft, the move time will be computed as a nominal value plus an adjustment based on the direction of the move, if diagonal. The nominal value is based on the required altitude change necessary to carry out its flight order. If the unit is not currently moving, the LSCHEK routine is entered to get LOS data for the aircraft. The unit control clock is set to the current time plus the time to move from center to boundary of the grid. It should be noted that the total altitude change occurs immediately, prior to the center-to-boundary move, while realistically this is not the case. The LOS check is computed using the new altitude at the old coordinates.

Data for air units are assembled on three forms: altitude data, air-mobility table, and ordered altitude. These tables contain the rate at which each of the possible three mobility classes of air units will travel in various situations.

When air units change altitude with little net horizontal movement (helicopters, vertical takeoff and landing (VTOL), or orbiting aircraft), such movement is measured in integral multiples of a standard altitude increment. This increment for vertical measurements is analogous to the horizontal grid size. A standard altitude increment is chosen as

input. An estimate is made and entered of the time required for each type of air unit to descend or climb one standard altitude increment. Other input is the maximum altitude of each air-mobility class. Maximum altitude possible is 4, 095 ft. above the highest terrain square. The last entry for each mobility class is the maximum altitude that the aircraft can fly during the battle. Altitude-change thresholds are entered for each air-mobility class.

For each air-mobility class, six altitude changes, designated alpha 1 to alpha 6 must be selected. Alpha 1, 2, and 3 are negative and the other three are positive. They have the following significance:

If the change in altitude of an aircraft as it goes from the center of one square to the center of the adjacent square is

Between alpha 1 and alpha 2, the flight path is a steep descent.

Between alpha 2 and alpha 3, the flight path is a moderate descent.

Between alpha 3 and alpha 4, the flight path is of negligible slope.

Between alpha 4 and alpha 5, the flight path is a moderate ascent.

Between alpha 5 and alpha 6, the flight path is a steep ascent.

Changes of altitude may not be less than alpha 1 nor greater than alpha 6 per grid square. (Alpha 1 is the most negative number in the set.) Such forbidden values would represent unreasonably steep dives or climbs.

Finally, movement rates (forward speeds) for each mobility index for each of the five altitude changes are entered.

Air units may be ordered to conduct either contour or level flight at any of three specified altitudes for each type of flight.

Input calls for movement rates to be specified by orders. If the rate at which the unit will move is not given the unit will move at its maximum rate. Seven rates are selected for air units. Each rate is assigned an index from zero to six, with zero denoting the slowest rate.

The ADJUST subroutine provides for an increase in time required to move diagonally from center to boundary of a square under some conditions.

When an attack helicopter is called for support by a command unit the helicopter will proceed to an ordered firing point, regardless of the locations of ground weapons, and perform a pop-up surveillance/firing action. The user should be aware that the model uses this procedure.

Comments on CARMONETTE route selection are the following:

Move times should not be artifically adjusted to accommodate the model's logical cycles (scan time, decision time, etc.). The cycles should be adjusted instead. This will become more of a problem should high-speed, fixed-wing aircraft be introduced.

A change in altitude for aircraft should be accomplished over time, rather than in zero time.

The MOVE routine should be modified to branch around those logic sections relevant only to ground units when considering aircraft.

EVADE

EVADE II requires that aircraft flight paths and ground site deployment be provided as inputs. Flight path representation consists of straight line segments described by points in X, Y, Z space. Aircraft never deviate from their assigned flight paths, but the airframe need not be aligned with the velocity vector if orientation angles are specified in the flight path data input (e.g., a helicopter in sideward flight while guiding a missile to a target).

Flight paths are selected manually. All terrain and flight path data are processed in the MASKPAS preparatory program for intervisibility determination. Terrain and flight path can be handled in separate steps, however, if the analyst desires.

Associated input preparation programs make extensive use of digitized terrain maps with small grid sizes. A 12.7 meter grid, minimum, is presently being utilized. A 40 x 47 km area of west central Germany

including about 12 million individual terrain heights is stored on magnetic tape for use with the intervisibility routine of the program. This area does not represent a maximum to the area coverage of the model; practically any area can be used, at the sacrifice of resolution, by skipping grid lines and "blowing up" the picture.

GLOBAL

Attacking units or weapon systems move from point to point in a three dimensional topographical grid. Movement of each unit is predetermined and input as a series of straight-line segments. Within a segment, direction, speed, altitude and visibility are constant. In this light, it is necessary to define a new segment each time one or more of the above constraints are adjusted. Extensive amounts of user analyst time is required to prepare attacking routine input data.

The game will end when the attackers reach the end of their paths. If the scenario provides that one or more of the attackers will start or finish earlier than the others, nonmoving, no-visibility segments must be added at the beginning or end so that each attacker spends the same time on the path. The route designation technique used by GLOBAL is highly detailed and contingent totally on the user's input data.

A large grid system is provided for the game -- $10^4 \times 10^4$ squares with optional scale. Using a fine 12.5 meter square size to define the resolution, an area of 125 x 125 km is possible. Only 30 x 30 km terrain representation is presently available.

No maneuvering actions are permitted upon detection of an enemy position or enemy fire. The decision is always one of three -- continue, halt, or retrace previous path segments until intervisibility is zero. (This last might be considered an escape maneuver. What happens during escape is not clear.)

The ground units are quasi-stationary, with no mobilities or routes specified but with displacement to new locations possible in response to near misses of incoming fire.

COMMENTS ON ROUTE SELECTION

Only CARMONETTE permits movement of the ground units.

While CARMONETTE uses flight paths that must be specified in orders, "skip orders" can be used to set up alternate paths.

CARMONETTE has fewer grid squares than the other two models, thus siffering in battlefield area when compared to EVADE II and GLOBAL.

LINE-OF-SIGHT

Prior to determining whether or not a target is detected by an enemy observer, the ability of the observer (or system) to actually see the target must be established. The primary factor considered to establish the visibility status is the possible existence of terrain in a position which blocks the observer's view of the target (masking). Other factors such as vegetation and weather may be included as part of the line-of-sight check or as part of the target acquisition routine.

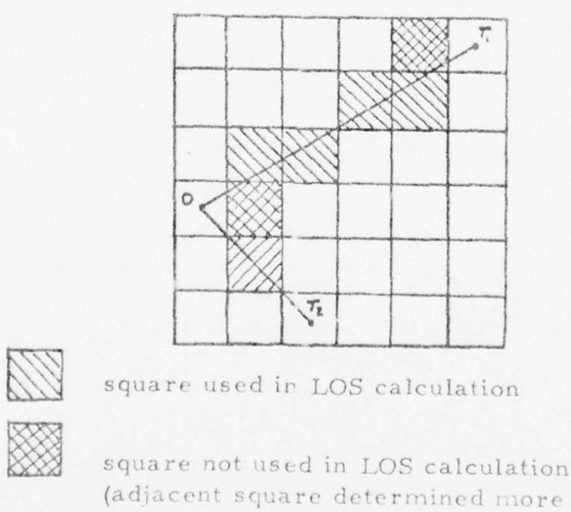
LINE-OF-SIGHT

CARMONETTE

The CARMONETTE model defines intervisibility as the physical condition of no intervening terrain or vegetation between an observer and a target. Intervisibility, in itself, does not imply target detection, only that an unobstructed line-of-sight exists.

The basic consideration in determining the existence of a line-of-sight is the slope of the line between observer and target. If any slope between the observer and the elevation of any intervening grid square is greater than the direct line-of-sight slope, then intervisibility does not exist. Line-of-sight always exists between adjacent grid square.

These slopes are easily computed if the line connecting the target-observer pair is either parallel to the terrain grid axes or on the 45 degree diagonal. In other situations a "staircase" algorithm is used to determine the intervening squares between observer and target. The operation of this algorithm is demonstrated below.



The shaded squares are checked for the possibility of intervening terrain between observer and target. The algorithm is designed to give the same results regardless of who is considered to be the observer, thereby satisfying the symmetric property of intervisibility.

Line-of-sight checks are made for all units in the second preprocessor to determine intervisibility at time zero. During the battle model simulation, a line-of-sight check is made against each enemy unit at the time a unit crosses a grid boundary, or when an aircraft is changing altitude.

An apparent discrepancy exists in the simulation of aircraft. Aircraft retain the LOS status of their last ordered destination. That is, if an aircraft is under orders to fly from grid A to grid B, it will not search for newly unmasked enemy units until it reaches grid B. Nor do these enemy units have a way of looking for the aircraft unless they cross a boundary themselves. Hence, the aircraft may fly between these two points without detection by stationary enemy units. This ostensibly was done to reduce computer running time but it can make helicopters blind and invisible while moving. In effect, the model logic assumes flight at treetop level away from enemy units. [The developers state that LOS is now checked at each boundary crossing. This change was made after the model was examined for this report.]

Furthermore, assume a red unit has crossed a boundary, performs a line-of-sight check, and detects a blue helicopter in grid square B proceeding from point A to point C. The helicopter may leave grid square B, but since no line-of-sight check is then made, the red unit will still believe it has visible contact with the helicopter. And it will continue so until the helicopter reaches grid C and performs a new line-of-sight check. Of course, actual line-of-sight may no longer exist after helicopter vacates grid square B. This may be critical for treetop-level helicopter altitudes.

Other discrepancies relating to aircraft line-of-sight computations occur when altitude changes are being made. There are three situations that fall in this category.

"Pop-up" to fire on target

Landing

Descent to treetop level

In the "pop-" algorithm, the minimum altitude necessary for the aircraft to achieve line-of-sight to the target is computed. Then the time needed to climb to this altitude is computed and stored in a simulation control clock. Immediately, however, a line-of-sight check is made using the objective altitude of the aircraft as its present position. Hence, during the aircraft's vertical climb, intervisibility between the aircraft and the target (and possibly other enemy units) is simulated, though, in actuality, it would not exist. It would seem more realistic in this situation to define some increment of altitude, and take a new line-of-sight check each time the aircraft climbed that distance.

A further comment on the CARMONETTE simulation of the "pop-up" tactic is in order. An attack helicopter will climb to the minimum required altitude and hover while searching for the target. It would seem that, in actual combat, the aircraft would not "know" its objective altitude and would continue climbing above the minimum while scanning for the target. This additional altitude might subject the aircraft to additional enemy observation and fire.

The simulation of landing an aircraft seems to present two problems. The first is that the aircraft may land from any altitude in one time increment (1/4096 min). The reviewers found no detrimental effects of this phenomenon other than the fact that the aircraft will be available for a subsequent mission much faster than is possible.

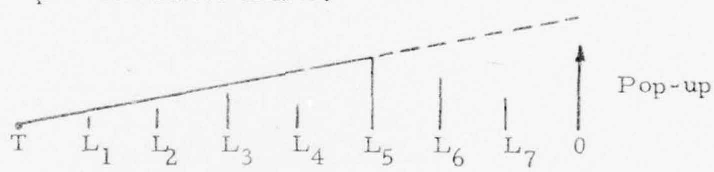
Secondly, no new line-of-sight check is performed upon landing. It appears, therefore, that the simulated intervisibility after landing is identical to the intervisibility at the aircraft's altitude before landing. (The game has been played to date with landing points and approaches out of LOS. When this is not true, proper account of the intervisibility effects must be made to obtain a better simulation.) [The developers state that LOS check is now made for helicopters when they are at treetop altitude and when they land. This change was made after the model was examined for this report.]

Treetop altitude is considered to be 5 feet above the terrain vegetation of a given grid square. A straight vertical drop to treetop level is similar to the "pop-up," and presents the same problem. The change in altitude is computed, the time to descend that distance is computed and stored in an event clock, and then an immediate line-of-sight check is performed, assuming that the aircraft has already reached treetop level. In effect, the aircraft cannot be "seen" while it is descending.

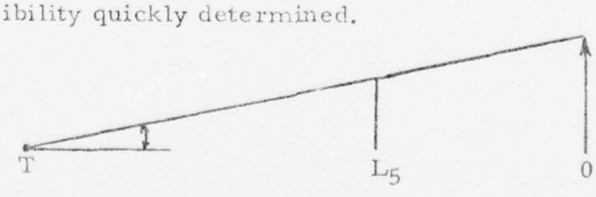
This would seem to be a major shortcoming in that helicopter tactics for evasion, both in the model and in reality, dictate a drop to treetop level if a sufficient amount of enemy fire is received. The model thus simulates an immediate escape from enemy observation if brought under heavy fire.

If the aircraft is moving across the battlefield, it will begin a sloping descent to treetop level if brought under fire. Again the aircraft's altitude is immediately set at treetop, but no new line of sight check is made. Nor, as stated earlier, will the LOS check be called when the aircraft crosses a grid boundary. It appears, therefore, that those units that were firing on the aircraft will "think" that intervisibility still exists.

Though very simple in nature, the pop-up subroutine contains some extraneous statements, and should be modified to reduce confusion. It also seems that the logic in determining the minimum altitude for line-of-sight is not the best procedure. Such iterative procedures are very wasteful of computer time, and, in this case, a rather simple alternative exists.



Working from the target square T, assume that the above lines represent height of vegetation for each intervening grid square to the observer. Each call to LOS, as the aircraft increases its altitude in increments, computes the slope between T and L_i, for each i. A simple modification to the function LOS would allow the program to store the maximum such slope. This slope can then be extrapolated back to the observer's grid square, and the necessary altitude for intervisibility quickly determined.



This procedure would save numerous calls to the LOS function, and would add a minimal amount of time to the internal execution of LOS.

EVADE

The model allows two methods of determining whether a target is hidden from a weapon by terrain. Both methods are essentially table lookup routines using externally generated flight path data. Masking calculations are performed for all weapon-type pairs within a liberally defined "range-of-interest" of each other. Targets masked by terrain are still subject to audible detection. Audible detection will reduce the reaction time at the ground gun when the target does become exposed.

The preferred method of checking for target masking used Z-List flight path data, generated by the U. S. Army Materiel Systems Analysis Agency's SEARCH routine, which indicates a masked or unmasked condition between the end points of each flight path segment and each ground site. Linear interpolation is used for masking events during a flight path segment. Z-List flight path data use digitized terrain and other factors as described in the model documentation.

The alternate masking model considers masking as a function of elevation above a ground site. The program accepts masking elevation angles at 15-degree intervals around the ground site. Each pair of elevation lines determines a segment of a plane. Aircraft above this plane segment, while in the corresponding 15-degree azimuth interval, are unmasked.

GLOBAL

Line-of-sight or enemy visibility is determined in the detection routine. Target visibility is defined for each path segment of an aircraft's flight path based upon the terrain. A three-dimensional grid system is superimposed upon a map of the terrain and straight-line path segments are laid out connecting the grid intersection points to represent the movement of the aircraft. For each path segment of the aircraft's predetermined flight scenario, a mutual visibility level is defined for each ground unit (input). A visibility level of zero for

a given path segment and ground unit is used to indicate masking of the geometric line-of-sight between the aircraft and ground unit pair during that segment of the aircraft's flight scenario. A non-zero entry indicates the existence of line-of-sight. The visibility levels affect the ability of a weapon to fire and the percentage of the hit probability used to assess the result of a particular fire mission. The percentage of the hit probability which will be applied is input data and is uniquely related to each of the visibility levels and the firing weapon system. Currently GLOBAL maintains six visibility levels, the zero level corresponding to no line-of-sight. The line-of-sight condition is not separable from the target acquisition routine in this model.

A stochastic positional error routine is included in GLOBAL. Signal points inserted in the path of a unit initiate a stochastic relocation of the point where unmasking occurs, thus reflecting the error distributions inherent in navigational systems and in estimation of future target position.

COMMENTS ON LINE-OF-SIGHT

Only CARMONETTE does not use precomputed intervisibilities.

CARMONETTE uses only one terrain height (plus vegetation) for each grid square. Thus, the terrain, as simulated, is that of a field of rectangular blocks of various heights. The other two models can use the intervisibility computed from the actual terrain map, breaking the flight path every time there is a change in line-of-sight condition.

TARGET ACQUISITION

This submodel determines whether or not a target is actually detected by any enemy observer or system. The three models reviewed use rather varied approaches to achieve this determination.

TARGET ACQUISITION

CARMONETTE

Information on enemy targets is represented by four intelligence states in the CARMONETTE model. These states are:

Target location unknown.

Target known within certain grid square.

Target is erroneously pinpointed.

Target is correctly pinpointed.

These target information states are considered to be a Markov chain process in that a set of information states and the transition probabilities between states are defined, a target can be in only one state at a time, and the probability of movement between states depends only on the current state. Information states are updated each "scan time," a small period of time input by the user. Three separate matrices of transition probabilities are used for each sensor class in the model. These define the probabilities for non-firing target (line-of-sight exists), any type target (no line-of-sight exists), and firing target (line-of-sight exists). These will be discussed in detail later in the report. First, consider the definition of a concept used throughout the detection algorithms.

Solid Angle - The solid angle subtended at the observer is defined as the exposed area of the target (cross section normal to the line-of-sight) divided by the square of the range to the target.

$$\theta = A/R^2$$

This definition conveys the simple relationship that a large target at great range is equivalent to a small target at short range. The user must externally calculate thresholds for solid angle based on area and distance.

Each of the three matrices previously mentioned will contain a number of sub-matrices for each combination of threshold solid angle, target activity, and observer activity. For example, in the case of a non-firing target, the model considers a combination of:

Solid Angle

$\theta < \alpha_1$

$\alpha_1 \leq \theta \leq \alpha_2$

$\alpha_2 \leq \theta \leq \alpha_3$

$\theta > \alpha_3$ where $\alpha_1, \alpha_2, \alpha_3$ are solid angle threshold inputs [A recent change, made after the model was examined for this report, incorporates the aspect angle for helicopters.]

Target Activity

Moving

Non-moving

Observer Activity

Neutralized by fire

Nonneutralized

Thus, the user must define 16(4x2x2) sub-matrices to cover each of the possible physical situations. Discussion will now center on a generalized sub-matrix, since all 16 will be identical in form, though probably differing in numerical content. Target contrast is an input quantity which apparently modifies the solid angle detectability ranges specified in the preceding paragraph. [The developer states that a recent change provides for a reduction of detection probability by 1/2 for a moving observer. This change was made after the model was examined for this report.]

<u>No Line-of-Sight</u> - The simplest case is that in which no line-of-sight exists between the target and observer. The transition matrix is then:

Current State	Subsequent State 1	2	3	4
1	1	0	0	0
2	P(LOS)	1-P(LOS)	0	0
3	0	1	0	0
4	0	0	1	0

The quantity P(LOS) is the probability that nearest square information is lost when line-of-sight does not exist.

It should be noted here that the sum of the probabilities in each row of the matrix must equal 1, which simply indicates that the target must go into one of the four information states. As seen in the first row, if the current state is 1 (no information known), it will (with probability of 1.0) remain in that state. No information can be gained if line-of-sight does not exist. For states 3 and 4, the information will be down-graded by one state each scan time if line-of-sight does not exist. This would seem to be a reasonable situation, but does call for careful selection of the scan time by the user. The only true probability in this matrix is then P(LOS). This probability is itself strictly a user-determined input.

Non-firing Target, Line-of-Sight Exists - This situation presents the most interesting and the most suspect of the transition matrices.

Current State	Subsequent State 1	2	3	4
1	P(11)	P(12)	P(13)	P(14)
2	P(21)	P(22)	P(23)	P(24)
3	P(31)	P(32)	P(33)	P(34)
4	P(41)	P(42)	P(43)	P(44)

Where P(ij) is the probability of being in subsequent state j having just been in a state i. The model documentation states that only six of these probabilities P(11), P(12), P(14), P(21), P(41), P(44) need be input, while the others can be derived algebraically. No derivation is given in the model documentation, however. From the computer code it was determined that the other probabilities are as follows:

$$P(13) = 1-P(11)-P(12)-P(14)$$

$$P(22) = \left[1-P(21)\right] \frac{P(12)}{1-P(11)}$$

$$P(23) = \left[1-P(21)\right] \frac{P(13)}{1-P(11)}$$

$$P(24) = \left[1-P(21)\right] \frac{P(14)}{1-P(11)}$$

$$P(31) = \frac{P(41)}{1-P(44)}$$

$$P(32) = \left[\frac{P(41)}{1-P(44)}\right] \cdot \left[\frac{1-P(21)}{P(21)}\right]$$

$$P(33) = \left[1-\frac{P(41)/P(21)}{1-P(44)}\right] \cdot \left[\frac{P(13)}{P(13)+P(14)}\right]$$

$$P(34) = P(33) \cdot \frac{P(14)}{P(13)}$$

$$P(42) = P(41) \cdot \frac{1-P(21)}{P(21)}$$

$$P(43) = 1-P(44) - \frac{P(41)}{P(21)}$$

Inspection of these equations shows that they do satisfy the one known matrix constraint, namely

$$\sum_{j=1}^{4} P(ij) = 1 \text{ for all i.}$$

However, no other basis for so defining these transition matrices has been discovered in this study. Other constraints, which are not specified, must be present. The above relationships apply only to the case of the non-firing target with line-of-sight. The matrix elements for the other two classes of target cannot be obtained from them.

Some shortcomings of the equations can be noted. Due to this formulation some constraints must be placed on input values.

$$P(11), \quad P(12), \quad P(21) \quad P(44) \geq .02$$

$$P(11) + P(12) < 1.0$$

$$P(41) + P(44) < 1.0$$

$$P(11) + P(12) + P(14) \leq 1.0$$

These constraints are noted in the documentation and are not particularly binding. It is of interest, however, that the .02 is strictly an artificial constraint due to the octal conversion and scaling of the data.

The equation for P(33) requires that $P(41) \leq (1-P(44)) \cdot P(21)$. Otherwise P(33) and P(34) will be negative. This constraint would seem to be more than somewhat artificial. In the CDC run examined P(41) is in most cases set as high as allowed by this inequality, indicating that the constraint is binding and may preclude entry of a more desirable value.

In summary, it is felt that the interrelationships among the various probabilities are neither intuitively nor mathematically apparent and should be further documented and explained by the developer.

Updates of the target information states for non-firing targets are based on the surveillance clock for a unit. A unit may have only up to two sensor types and each sensor has an associated scan time. Thus, once each scan time the surveillance clock will trigger a call to the TGTACQ subroutine which updates the information according to the previously discussed matrices.

Firing Target - Line-of-Sight Exists - According to the available documentation, the transition matrix shown below is used for tracking a firing target.

Current State	Subsequent State			
	1	2	3	4
1	P(11)	0	P(13)	P(14)
2	0	P(22)	P(23)	P(24)
3	0	0	P(33)	P(34)
4	0	0	0	1

This upper triangular matrix implies that information cannot be degraded if the potential target is firing. Analogous to the previous case, only P(11) and P(14) are said to be required as input data. The present data input forms require the values P(13) and P(34), however. No additional matrix elements are computed, except the implicitly known (1-P(13)) and (1-P(34)), since each row must sum to 1.

If one continues to assume the validity of the upper triangular form in this situation, one can develop the matrix with the further assumption that P(23) = P(13). The program logic of the POSDIS (position disclosure) subroutine seems to bear out this formulation. The POSDIS routine is called each time a unit fires, if that weapon has a firing signature.

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Current State	Subsequent State			
	1	2	3	4
1	1-P(12)	0	P(13)	0
2	0	1-P(23)	P(23)	0
3	0	0	1-P(34)	P(34).
4	0	0	0	1

The inconsistency evident here is that the information cannot be upgraded from state 1 (or 2) to state 4 while the target is firing, yet it was possible for a non-firing target. The program is written so that if the target is in state 1 or 2, the firing of the first round by the target will only permit a state 3 to be reached. On the second and subsequent firings, state 4 can be obtained. Also, if the target is in state 3 beforehand, the firing can only produce no change or a transition to state 4.

Target acquisition is defined internally as gaining nearest square intelligence on an enemy unit. It may be accomplished by either Command, Control, and Surveillance (CCS) units or weapons units. The CCS units have no weapons and are not subject to fire, but have an associated "buddy unit" which is a weapon unit. The CCS unit accompanies the buddy unit and moves in accordance with that unit's orders. (The carrier may be common.) CCS units are limited to acquiring the nearest-square level of information, while only the weapons units are capable of acquiring higher levels.

A CCS unit thus does not enter the target acquisition routine. Instead, the CCS, upon detecting a target through the surveillance routine, provides nearest square level of information to its higher headquarters and to its weapon unit. Each such transfer of intelligence occurs after a time delay (communication cycle) specified by the user.

A weapons unit enters the target acquisition routine after each scan interval. If LOS exists to the target, the weapon unit would incur a

change of intelligence state in accordance with the appropriate transition matrix element, as outlined earlier. If nearest square intelligence had been previously provided by a CCS unit, then that would be the starting point for the current intelligence transition. If a weapon unit acquires erroneous pinpoint or exact pinpoint location of an enemy unit, this intelligence is immediately passed to its CCS unit for further dissemination at the end of the communication cycle. The intelligence passed along is only nearest-square information, however, as CCS units are not capable of higher level.

A weapon unit does not communicate when it obtains nearest-square information. The rationale for this is not made clear and is questionable. This would seem to be as important as pinpoints, since all information passed to the CCS unit is considered to be at the nearest-square level.

If LOS does not exist between a weapon unit and a target, then the change in intelligence state of the weapon unit would depend on its previous state of intelligence and on a user input probability of losing nearest square level of information. An automatic reduction of intelligence would occur if the weapon unit had either erroneous pinpoint or pinpoint information, whereas if the unit had nearest square information, a further reduction would depend on the user input probability mentioned. Some of the required data for these routines (VISDET and IMADET) and for the RADAR routine are target reflectance, background reflectance, target dimensions, target speed (for RADAR), and device characteristics.

Comments on the target acquisition submodel of CARMONETTE are the following:

The specification of "Target Class" by the user should be made carefully, since target reflectance should be nearly equal within each class when the model includes visual or image intensifier detection devices.

The RADAR routine should be investigated. That routine uses certain coefficients and constants which apparently have no physical units. These constants are internal to the model, but their origin or meaning is not specified.

The VISDET and IMADET routines do not distinguish moving targets from stationary targets, although this condition may be an important factor in the detection.

The IMADET routine has a local constant (CG = 0.75) used in the computation of received contrast. This constant is not documented.

Sensor classes 1, 2, and 4 are internally defined in the SURV routine to be visual, image intensifier, and radar, respectively; whereas the available documentation does not suggest any predetermined definitions. Sensor class 3 has at some time been defined as thermal, since documentary comments in the program so state. It is not now a reserved class, however.

The user provides a probability of loss of nearest square information when LOS is lost. It is not clear how this value is determined, but this is a good concept.

If the target is not within the min/max sensor range, than that target will not be detected and the program will skip back to examine the next target. However, the next program statement would have set the detection probability to 1.0 if the target and sensor were in the same grid. For most cases, it would seem reasonable to reserve the positions of these two logic statements in the program.

A weapon unit with sensor class 1, 2, or 4 could have a target placed in its nearest square detection list in the SURV routine and also proceed through the TGTACQ routine in the same time frame, thus passing through more than one intelligence state transition in one time period.

For CCS units, if the associated buddy (weapon) unit is responding to fire, then the unit will perform surveillance with a fixed probability of 0.50. If surveillance is not performed, then the CCS will lose nearest square intelligence with a fixed probability of 0.50. These probabilities should be user controlled, and should be provided for each CCS unit as appropriate.

[The developer states that, after the model was examined for this report, a change was made in the surveillance routine. This provides that an observer will restrict his search to the near vicinity ($\pm$ 2 grids) of the closest first-priority target of which he has any knowledge.]

The documentation indicates that weapons units are limited to visual detection devices but that CCS units can use any of the six sensor classes. Investigation of SURV shows that this is not the case; weapons units are not so limited.

The documentation should be updated to accurately describe the sensor routines. The meaning and origin of constants in these involved routines should be discussed.

Some subroutines in CARMONETTE on target acquisition incorporate procedures for computing exponentials which are now standard software items, but were not available when these earlier subroutines were written. Some updating of these earlier subroutines would benefit the program.

Consideration of whether or not the target is moving should be a factor of detection in the VISDET and IMADET routines.

The target detection algorithms begin with fundamental engineering principles and equations and could not be judged adequately by the reviewers of the simulation, although there is no reason to doubt them. It is suggested that empirical relationships derived from these engineering models would satisfy the requirements of CARMONETTE just as well and would be more visible to the user and more flexible.

EVADE

EVADE II evaluates the ability of ground targets to detect aircraft as a function of terrain masking and, when the target is unmasked, as a function of radar range, visual detection (including glimpse), and acoustic range.

There is no air-to-ground detection submodel in the program. Computations concerning detection of ground targets by aircraft consider terrain and vegetation masking. All ground weapons are visible and the pilot is able to detect all weapon sites that are unmasked, subject to a delay time which is input. Values for this delay time are derived from field test data.

The ground-to-air detection routine is simple in its approach. It is also one of the few routines of this type which have been validated by correlating with field test detection data. The much more sophisticated

and complex VISDET 2 routine is available but will not be utilized until certain discrepancies in its data base become corrected. It includes motion "cues," smoke trails, and ephemeris of the sun (to evaluate glint and sunglare).

Radar detection routines in EVADE II compute distance and elevation from a ground site in a very general way for unmasked aircraft targets. These values are compared against a table of user supplied data showing effective radar range as a function of the same two variables. Linear interpolation is used when required. These routines assume an unlimited ability to distinguish targets from background noise. The model does not attempt to examine detailed radar characteristics and properties.

EVADE II contains two routines concerning acoustic detection. The preferred and somewhat detailed routine performs a table lookup against user-provided data containing 25 acoustic ranges, azimuths measured from the direction of flight of the aircraft, and aircraft type. The externally generated acoustic footprints must already include factors such as velocity, aircraft altitude, vegetation, etc., prior to entry into EVADE II. Ambient noise level and temperature are included with the acoustic signature input.

The alternate acoustic detection routine is very rough; it assumes that detection occurs at a fixed range and tests to see if an aircraft is in range. The acoustic acoustic detection range is supplied by the model user.

Acoustic detection of an aircraft by a ground site serves to reduce the weapon reaction time for that site from 0 to 25%.

EVADE II offers two methods of considering visual detection of aircraft by ground sites. The preferred method uses a modified version of an ECOM model and is coded into the program. The alternate method simply assumes that visual detection always occurs at a fixed range, with the range being supplied as user input.

The ECOM visual detection routine is well described in EVADE II documentation, Book 1, Volume II. Analyst Manual, pp. 2-8 through 2-17. It begins with a calculation of the angular width of the aircraft

at the observer's location. The assumption is made that one minute of arc is the best the eyeball can do, in terms of angular size, at the fovea (the center of the retina). The minimum detectable angular sizes are then known for the annular ring regions around the fovea; these are tabulated in the documentation. Assuming that the observer looks at random over a hemisphere, the probability of an image falling in a particular annular region of the retina has been precalculated and tabulated. (The model divides the retina into 15 of these concentric rings.) The angular size of the aircraft produces a probability of detection of either 0 or 1.0 in each of the 15 annular retina regions. The program then computes the probability of detection in a glimpse by summing up the products of the latter two probabilities for all of the retina regions. Another way of saying all this is that the probability of glimpse detection is the probability that the image will fall on the portion of the eye retina capable of detecting an object of the angular width of the distant aircraft. Glimpses can accumulate to build up higher detection probabilities over time. The amount of time given to this is specified in a routine called TLOOK. Modifications for ambient light level and atmospheric light transmission are included.

The VISDET 2 model is the only presently available model which shows promise of becoming both operable and in agreement with its data base. When this occurs, it will be included and the ECOM model will be removed. It includes sun ephemeris and several other important aspects of the detection process.

GLOBAL

At every time step in the simulation, all game units are first processed in the detection subroutine. This subroutine resolves whether or not detection has occurred for all combinations of air-to-ground and independent ground-to-air unit pairs that have geometric line-of-sight during the current time interval. Stochastic decisions are made for each game unit to determine which of the enemy units were detected during the current time interval. An enemy unit that is detected remains on the list of detected targets until it is masked or killed or until the game ends. The primary concepts treated in the detection subroutine are intervisibility of units, selection of appropriate detection probabilities from input tables, calculation of apparent target area using the geometric line-of-sight,

stochastic evaluation of whether visual detection has occurred, and provision for enabling an aircraft to scrub an attack from a pre-planned launch point upon detection of a scrub-causing ground unit that has recently fired.

Units which do not detect potential targets repeat the detection subroutine in each subsequent time increment until targets are detected. Once a target is selected, acquisition delays are considered by GLOBAL; these are contingent upon the weapon type. Acquisition delay times are initiated in the simulation programs from pregame input data.

No consideration is given by GLOBAL to increasing the probability of detection of an enemy unit that was previously detected and then masked in later time periods. Once LOS is lost to a detected unit, forcing a new detection, the second detection may be easier or have a higher detection probability. A solution of this shortcoming would be to program checks for second detections and associated times for second detections; a higher probability for second detection, as a function of the time period between detections, could be allowed.

TARGET TRACKING

The ability of an observer or system to follow a moving target is simulated in this submodel.

TARGET TRACKING

CARMONETTE

No target tracking in the usual sense is done in CARMONETTE and there is no subroutine specifically for this. However, by thinking of target tracking as maintaining the pinpoint target location, one can refer back to the discussion of CARMONETTE target acquisition to see how tracking is handled. The probability of loss of pinpoint is the P(44) matrix element which is input for various situations. This is a weak substitute for a true target tracking simulation; it is in the intelligence domain, applying equally to all moving and stationary targets. A different target decay scheme for moving versus stationary targets of the same kind and for different target types and sensor classes would seem more reasonable.

EVADE

EVADE II uses a rather complex system of selected sampling of fire control errors to account for gunner misestimates in speed, range, course angle, and dive angle. The "Salvo Fire" attrition equations further account for aim bias errors, ballistic errors, and bias errors due to a maneuvering target. This methodology has been extensively checked against the other five most widely accepted aircraft attrition models in the analytical community. All this methodology, its background and its history are spelled out in the EVADE manuals. The methodology and handling of fire control variables is reasonably rigorous and appropriate for range-only radar, full solution radar, and optical systems.

A ground weapon can begin crude (rough) tracking of an aircraft if it can hear it and no other unmasked targets are available. The ground gunner can thus be given credit with knowing the approximate location of a masked aircraft (field test data indicate that under favorable conditions a gunner can track acoustically to within plus or minus seven degrees accuracy).

If, in the simulation, an aircraft remasks for a brief time while a ground gun is engaging it, the gun is given credit with still knowing the

aircraft's location and will continue to track for several seconds (similar to the "coast" network in most AA fire controls). The ground gun will not track an unmasked aircraft if detection has not occurred.

GLOBAL

The GLOBAL logic does not contain a target tracking capability per se. However, once an enemy unit is detected it remains detected until the unit is masked or killed. If the enemy unit is masked, it is processed through the detection subroutine at later simulation time intervals as discussed in the TARGET ACQUISITION section of this review.

FIRING DECISION

The decision to fire on a target is based on a number of interwoven events and priorities. The criteria and logic used for engaging the "best" targets are explained in this section.

FIRING DECISION

CARMONETTE

The firing decision logic in CARMONETTE is probably more complex than any other model. The present treatment is necessarily cursory. The firing decision logic is contained in the subroutine TGTSEL. Part of the orders provided each unit indicate the kind of fire and the priority rules to be applied by each weapon type assigned to the unit.

There are seven kinds of fire as shown below:

No fire.

Suppressive fire at grid X, Y or at pinpointed targets within it.

Suppressive fire at grid X, Y or at pinpointed targets within it, while firer is moving.

Fire at pinpointed targets anywhere.

Fire at pinpointed targets in grid X, Y.

Fire at pinpointed targets anywhere while firer is moving.

Fire at pinpointed targets in grid X, Y while firer is moving.

Suppressive fire at a grid is superceded if the firer has a pinpointed target. Erroneously pinpointed targets are indistinguishable by the firer from accurately pinpointed targets. In order to be considered, the target class of the enemy unit must be one of the six target classes identified by the firing weapon's current priority rule. Unless the kind of fire permits firing while moving all units must halt to fire. The rules for the decision to stop and fire were presented in the discussion of the route selection submodel.

Six priority rules are available for each weapon type. Three rules consists of priority lists of up to six enemy unit target classes. In addition to the priority lists, each firer is assigned to a vulnerability class. A range-dependent determination is made of the vulnerability of units in the same vulnerability class to each enemy target class. Three range bands are defined and each vulnerability class is defined as either seriously vulnerable, moderately vulnerable, or effectively invulnerable to each enemy target class in each range band. Two rules define whether the unit should first use its vulnerability to enemy units or its priority list to screen the available targets and make its firing decision. Thus, each unit may employ either vulnerability first or priority first and up to three priority lists, for a total of six target priority rules. If after applying both the priority list and the vulnerability criterion more than one enemy target unit still remains, the firer-to-target range criterion is applied. This criterion, to either select the nearer target or the farther target, is at the option of the user and is defined for each unit by input. If two targets still remain at the same range then a random number is drawn to select one of them.

Also considered are command control and surveillance (CCS) units. These units do not fire, but may call artillery or attack helicopters. If the CCS unit can call for helicopter support, then a check is made on available aircraft, nearest square targets, and the target priorities. If aircraft are available, and the target list contains a target for which nearest square intelligence exists, the CLHCPR routine will be called. In the CLHCPR routine, the target closest to the CCS unit that is not now being attacked by aircraft will be selected. The CCS unit will attempt to call one of its own subordinate aircraft units. A basically similar procedure is employed in calling for artillery support (CLARTY).

Some of the observations on TGTSEL are as follows:

> One kind of fire (code number 2) is not defined.
>
> Array LASQ is defined in the Treatment data as permissible deviations from ordered square (XX, YY) for which point firing may take place.
>
> The complexity of the decision in selecting targets suggests that "aim time" should perhaps be increased when several candidate targets exist. Also, the tie-breaker logic would suggest the same possibility.

"Aim time" is doubled by routine DESTGT if the unit is pinned down.

The allocation of men in the "suppressive fire" submodel should be investigated closely.

Suppressive fire is always performed with type 1 ammunition in the suppressive fire submodel.

Weapon category 5 is designated as being able to fire final protective fire. [Developers state that this no longer used.]

The FIRING routine simulates the firing of the weapon by resetting the weapon code and clock and, if reloading before impact is permitted, by resetting the loading code and clock. This routine also adjusts the amount of ammunition remaining to the unit and accumulates the number of shots fired by the main weapon group in order to implement the unit's orders.

Firing may be terminated for several reasons:

The unit is moving but firing while moving is not permitted according to the unit order.

There are no men to fire the weapon.

The unit has a point target but either the unit does not have at least erroneous pinpoint intelligence on its target or the target is known to be dead.

The target is not within the min/max weapon range.

LOS to the target or area does not exist.

The unit has no ammunition.

If no other weapons have a target, the weapon clock will be changed to the current time plus 1, and the weapon code will be reset for target selection.

The FIRING routine also may call the CHANGE routine. That routine gives the unit a chance to change its mission after a round if the weapon being processed is the main weapon, if the weapon does not require guidance, and if one of the following obtains:

> The unit runs out of ammunition and the unit has out-of-ammunition orders.
>
> The maximum number of rounds has been fired at this target.

The FIRING routine also calls the POSDIS routine if the fired weapon has a firing signature, so that enemy units can obtain intelligence.

The mode switching logic sections should be investigated, with emphasis on the ammunition accounting. The developer agrees that this routine is wrong, but says that the simulation of mode switching weapons has not been done for a long time and that the routine is always bypassed now.

EVADE

Ground Weapons

At a given time during an engagement a ground weapon site may be able to engage more than one aircraft. Which aircraft is engaged under these circumstances is controlled by engagement rules. One of four rules has to be specified for each ground weapon position. Each weapon position may use a different classification for "priority" targets, identified as either troop ships or gun ships, whichever is more desirable as a target.

> Optimum Target - Under this option, gunner selects the target he estimates (based on aircraft's position, direction and velocity) will remain inside the maximum effective range of his weapon for the longest period of time.
>
> Closest Target - The aircraft engaged is the one closest to the ground weapon site at the time the selection is made.

Priority Target - Gunner will engage any priority target within range. If more than one priority target is in range, he will use either the optimum target rule or the closest target rule to decide which priority target to engage. If no priority targets are in range, gunner will use either optimum target or closest target rule and engage a non-priority target.

Priority Target Only - This rule is the same as the priority target rule except that if no priority targets are in range, the ground weapon will remain inactive.

An already engaged gun does not automatically drop its target when it comes under fire from another source. This is not realistic under some circumstances. Whether or not it should do so depends upon many time dependent engagement parameters. In general, standard air defense rules of engagement are employed, however.

Air Weapons

The computer makes the following checks:

Ammunition remaining.

Aircraft remaining on flight path.

Flight path not complete.

Ground target within range of interest (input by weapon type).

Ground target within maximum effective range of air weapon.

Ground target unmasked.

Aircraft will not fire on suppressed targets unless there are no other targets and the aircraft weapon has at least 50% of its basic load of ammunition.

The model checks to determine if the aircraft weapons can be brought to bear on the ground target. Aircraft maneuvers to fire on the target must be preprogramed as input. The main restrictions are roll angle, right/left side fire only, maximum angular turn, and elevation/depression of the gun. Any air weapon can be fired with full consideration of turret angle limits.

In selecting targets, the ground target is evaluated in accordance with set of engagement rules. The targets are weighted by the use of a target desirability factor. The targets are then sorted and the target having the highest numerical value is selected. Weapons effectiveness is adjusted, when appropriate, to be proportional to the probability of survival of the weapon. The model selects the "best" air weapon to be used on each ground target.

In the actual firing routine, the first check is to determine readiness of ammunition. If magazines require reloading and ammunition is available, they are reloaded. Striking velocity and trajectory of projectiles are then looked up in a table or computed if tables are not available. Physical limitations of gun mounts are checked to determine whether or not the gun can be brought to bear on the ground target. Masking, as well as maximum and minimum range checks are made. There is a time delay corresponding to damage assessment time.

GLOBAL

The decision to fire is made by the GLOBAL SELECTION subroutine. The function of this subroutine is to validate targets for the prospective firer currently being processed and to add various acquisition and firing delays to the game time. In order for an enemy unit to be a valid target it must be alive, visible, detected by the firer, inside the firer's angular firing sector, and of an appropriate target type for the firer's weapon type.

The second major function of the SELECTION subroutine is to select the best target from among all valid enemy units for the prospective firer. The general selection methodology available to air and ground firers consists of computing a numerical priority value for all valid targets. This number is computed using the target's base priority

number given in the input data, with zero assigned to the best and nine to the least desirable target, and then increasing this number by one for each additional "range interval" (input variable) to the target and by three if outside the firer's preferred firing sector. The target with the lowest numerical value is selected as the best or highest priority target. In summary, a decision to fire is made based on target closeness, priority, and visibility level.

An alternative mode of selection, available only to aircraft, provides that the firer select the first valid target on a preferred list of enemy units defined in the input data and arranged in descending order of preference. The order of preference may vary for different route segments if the model user intends each aircraft to select different ground units from scenarios with closely deployed ground units.

It is significant to note that, when defender or attacker weapons begin firing, firing will continue at the given rate (input) and at the same target until the target is no longer available. Cease fire criteria are as follows:

Target killed

Target suppressed

Target out of range

Loss of LOS

Target outside the firer's firing sector

Simulation ends

Higher priority target is acquired

Ammunition is expended

If one of these occurs, the target selection process is repeated or new detections are processed.

SUPPRESSION OF GROUND FIRE

Suppression of fire means causing a unit to stop firing by firing at it and causing the crew to take cover. This section is devoted to the suppression of fire from ground units only; a separate section treats the aircraft response to fire. The simulation of suppression is difficult because of its psychological aspect. (Morale is another of those intangibles that no one tries to include in simulations.) Nevertheless all three of the models do recognize suppression and try, in varying degrees, to come to grips with it.

SUPPRESSION OF GROUND FIRE

CARMONETTE

Suppression takes three forms in the CARMONETTE simulation; it restricts movement, firing accuracy, and surveillance. Addressed in this section are those suppressive effects helicopters may inflict on enemy ground forces.

There are three steps associated with suppression. First, each ground unit is placed in one of four fire response classes. These roughly correspond to the following:

Heavy armor

Light armor

Unarmored vehicles

Dismounted infantry

Secondly, these units may undergo three categories of suppression:

Pinned down

Partially neutralized by direct fire

Partially neutralized by indirect fire

Thirdly, threshold values are input by the user for each of the twelve combinations of fire response class and suppression category. If the weighted number of incoming rounds exceeds the threshold value, the unit is suppressed. In the sample run reviewed, the weights ranged from 1 for a rifle to 7 for howitzers (7 is the largest possible value). The effect of neutralization is a reduced capability for firing and a reduced capability for observation.

Actions of this nature are handled by the subroutine RESPNS. Activation of this subroutine is triggered by the decision cycle and the surveillance cycle. Hence, before each decision and each attempt at surveillance, the simulation determines to what extent the unit has been under fire and how that fire may affect the unit's actions. Note that even if a unit were to come under an infinite amount of fire, no action would be taken until either the decision interval or the surveillance interval has elapsed. In effect, a unit does not know it is being fired on until the end of one of those cycles.

A pinned down unit cannot move for a time determined by input, one decision cycle or longer. After that time it will reevaluate its position. A pinned unit also automatically "assumes a lower profile." This is handled in the program by increasing the unit's cover, thereby decreasing its exposed area. A partially neutralized unit cannot accurately fire, but may move from its position. A unit in any suppression category experiences a greatly reduced surveillance capability, resulting in loss of intelligence about the enemy. Armored vehicles cannot be pinned down by enemy fire. [The developers state that a recent change reduces all intelligence possessed by a pinned-down unit to the nearest square only and also prevents the unit from doing surveillance. This change was made after the model was examined for this report.]

EVADE

The EVADE II documentation indicates that ground units are suppressed by fire when the cumulative buildup of kill probability against them reaches a predetermined level (an input quantity). Missing from the documentation is mention of suppression times (given as input) during which the ground weapons are prevented from firing.

GLOBAL

Suppression is simulated by the GLOBAL model in its damage assessment subroutine. The suppression factor results from a miss, in which case an appropriate suppression probability is selected from a table; this probability depends upon firing weapon type, target type, and range. A newly selected random number determines whether suppression has or has not occurred through comparison with the suppression probability. If suppression is present, the ground weapon is silenced for a predetermined time. It is also prevented from detecting or selecting targets during this time. (This time may be

zero for those weapons predefined to be not suppressible.) Provision is made for a ground unit to displace to a new location during the suppression time, if desired. It should be noted that suppression resulting from a near miss gives no consideration to previous misses or volume of fire. If suppression is considered to be a significant feature by the model user, it is recommended that a check on fire volume and previous near misses be programed into GLOBAL logic with an appropriate increase applied to suppression probability when such checks are positive.

COMMENT ON SUPPRESSION OF GROUND FIRE

CARMONETTE makes the most elaborate provision for the suppression of ground weapons. However there are at this time no test data or other means to establish the validity of any of the judgmentally derived thresholds or times used in the suppression model.

AIRCRAFT RESPONSE TO FIRE

The aircraft under fire from the ground will have various options, the most significant being to seek a masked location. The response to fire can sometimes jeopardize the mission and there are psychological factors at work here too, as there are for the suppression of ground fire. All three models address the response to fire problem, but in different degrees of detail and with different emphasis.

AIRCRAFT RESPONSE TO FIRE

CARMONETTE

Response to fire by aircraft is based on the weighted number of incoming rounds received in a given interval of time exactly analogous to ground weapons. This interval is the "neutralization" period, a user input value. The threshold for incoming fire is also input by the user. In the test run reviewed, aircraft take evasive action if more than 60 weighted rounds are received during a firing run or more than 50 weighted rounds if not on a firing run. The weights arise from each weapon in the simulation being given a relative neutralization effect by the user.

Aircraft response to fire depends upon the movement characteristics of the aircraft at the time. If the aircraft is moving and incoming fire is greater than the threshold value, the following take place:

> Aircraft continues movement toward objective with gradual drop to treetop.
>
> Firing accuracy is reduced.
>
> Observation capability is reduced.

If the aircraft is hovering over a grid square and the threshold is exceeded it will do the following:

> Drop to treetop level.
>
> Abort present mission.
>
> Wipe out memory of fire received.
>
> Begin moving toward new mission.

For some past runs of the model, aviation experts in ACSFOR requested that missions of helicopters not be aborted during the missile guidance phase. No program coding was discovered that would correspond to this request.

The subroutine NEUT is used to update a unit's memory of incoming fire every 1/3 neutralization interval. Information is simply aged and forgotten at the end of the third subinterval. No weighting factors are used to show relative importance of new information.

EVADE

Aircraft response to fire follows the rules of engagement provided by the user as input. Under most conditions, these rules are set up so that the air gunner will engage the target closest to the front of his aircraft. If he is receiving fire from a ground weapon site at close range, he will use his 30mm gun in preference to a TOW. Evasive maneuvers must be preprogramed, as stated earlier, so the model does not provide for a complete response to fire in a dynamic sense.

GLOBAL

GLOBAL simulates aircraft response to a limited extent through its mission scrub routine. *Detection, through fire or otherwise,* of a ground weapon capable of inducing a mission scrub will give the aircraft the option (preprogramed) to seek a protected flight path.

COMMENT ON RESPONSE TO FIRE

Truly dynamic response to fire is available only in the CARMONETTE model.

ASSESSMENT SUBMODELS

The assessment submodels include firing accuracy and attrition. These are discussed in the next two sections.

FIRING ACCURACY

Firing accuracy routines deal with the ability of a weapon to hit a target with a projectile fired as a single shot or in a burst of rapid fire. Some models tend to treat this in gross manner, using simple hit probability tables, while other models calculate hit probabilities internally, using detailed factors influencing the outcome.

FIRING ACCURACY

CARMONETTE

The CARMONETTE documentation on the formulae and algorithms for computing firing accuracy (hit probabilities) contains a number of errors and inconsistencies. The actual coding in the programs is considerably better than the documentation.

The documentation contains a sign error in the equation which defines hit probability as a function of range for a dispersion pattern centered on the target. This error is not present in the coding of the program. The correct expression should read:

$$P(R) = 1-\exp\left[-r^2/2(s(R))^2\right]$$

Values of s(R), the total dispersion as a function of range, and input for each of 12 conditions and two ammunition types permitted each weapon. The parameters comprising these 12 conditions are:

> First round, subsequent volley with previous hit, or subsequent volley with previous miss.
>
> Target moving or not moving.
>
> Firer partially neutralized or not.

For each condition, the user specifies the total dispersion deviation at maximum range, at 0.707 maximum range, and at zero range. (In actuality the user will have to extrapolate back from minimum range to obtain the zero range value.) A parabolic curve is then fitted to these three points in order to evaluate the dispersion at any given range. The documentation contains an incorrect expression for this curve. Again, the program itself uses the correct expression, which is:

$$s(Q) = a + \left[(b-a)/(M/2)\right] Q + \left[(c-2b+a)/(M/2)\right] (Q/M) \left[Q-(M/2)\right]$$

where
a = the dispersion at zero range
b = the dispersion at .707 maximum range
c = the dispersion at maximum range
M = the square of the maximum range
Q = the square of the range to the target.

The IHIT subroutine contains a constant factor, 1024, in its calculations. The reason for using this factor is not clear and an explanation is missing in the model documentation.

The calculated hit probabilities must be mapped into the interval 0 to 64 since the CARMONETTE random number generator produces a six-bit result between 0 and 63 (64 indicates a never-miss probability). This was discussed earlier in the STORAGE section of this report. The subroutine to accomplish this mapping produces deviations from the monotonic relationship which must exist between dispersion and hit probability. A correction to this subroutine is necessary. [This correction has been made since the model was examined for this report.]

Finally, an easily overlooked data dependency should be brought out. Computations of hit probabilities are dependent on the grid size chosen by the user. All units are considered to be at the center of their grid, so all ranges will be in terms of grid size. The smaller the grid size chosen the more accurately the range and dispersion may be stated.

EVADE

For ground weapons, the firing accuracy is a part of predictor routines which simulate an air defense weapon's fire control ability to receive current target aircraft information and combine it with bullet flight time to predict the gun aiming line, reflect the gun's ability to maintain the desired aimline, reflect the ability of a fired bullet to stay on course, and measure the critical aircraft-bullet displacement used in subsequent effectiveness calculations. The results of the predictor routines combined with target vulnerability data serve as the independent variables in the formula for the probability P(k) that the aircraft is destroyed.

Basic information required as input to the predictor routines and P(k) calculations includes target aircraft description, air defense system data for the engaging air defense gun, and flight path history. Each aircraft when treated as a passive target is represented by a set of vulnerable components and each vulnerable component is described by six vulnerable areas, one for each cardinal view. Values assigned to these vulnerable areas are required computer model input data and are tabulated in terms of bullet type and bullet striking velocity. A program option allows the vulnerable area to be specified as a function of azimuth and elevation about the aircraft as well as striking velocity. Air defense system input data include the fire control location, defined in a three-dimensional engagement coordinate system, and the fire control current-aiming-line prediction, described by azimuth and elevation angles. It includes the gun location, when the fire control is off-carriage, and pertinent weapon characteristics such as ammunition capacity, firing rate, burst size, slew rate, track rate, settle time, tracking error formula constants, ballistic dispersion data and bullet time-of-flight formula constants. Each flight path is described in the input by a series of points located in terms of the engagement coordinate system. Additional information supplied for each flight path point includes aircraft speed and roll angle. Straight line segments between adjacent points are assumed throughout these routines.

The draft EVADE II documentation is quite clear and thorough on this subject.

The treatment of firing accuracy for air weapons against ground targets is much simpler, being merely a table look-up procedure. For weapons requiring continuous line-of-sight from firing to impact (TOW), a check is made to assure that this condition exists.

GLOBAL

The firing accuracy of a weapon is specified via a hit probability, P(h), which is an input quantity. For each defending ground weapon, the P(h), is given as a function of weapon type, target type, range, and attacker heading. Comparing P(h) with a random number scores a hit or miss depending upon whether the random number is less than or greater than P(h). For attacking air weapons, the procedure is the same except that attacker heading is not brought in. The exposed area of ground targets and the visibility level are considered.

COMMENTS ON FIRING ACCURACY

The line-of-sight check during projectile flight in the EVADE model is useful for playing the TOW. It is a feature that should be incorporated into the other two models. [CARMONETTE developers state that a final LOS check at time of missile impact is used in their model to abort the missile when LOS has been lost.]

The CARMONETTE procedure of computing hit probability from scratch for every firing is unnecessarily complicated and probably adds nothing to the accuracy of the determination. Misses due to aiming error, weapon sight-correction error, and wind will place the center of the dispersion pattern off the center of the target in most cases anyway, making the entire calculation of P(h) open to question.

ATTRITION

The subject of attrition includes any mechanism for removing elements from the battle, whether by outright kill or by damage of equipment. It is distinct from hit probability determination, although the determinations of hit and kill or damage may be combined in some models. All three of the models employ probabilistic techniques for attrition.

ATTRITION

CARMONETTE

CARMONETTE considers the probability of kill given a hit after progressing through the firing accuracy logic described in the previous section. If a hit is scored, the logic of this section will determine if the target was killed. Indirect fire weapons are considered to always hit within a user-defined impact area. Five types of attrition are considered:

> Vehicle casualties (including aircraft)
>
> Casualties to mounted troops
>
> Effect of indirect fire on vehicles
>
> Casualties to exposed infantry due to fragmentation ammunition
>
> Casualties to infantry from nonfragmentation ammunition

[The developer states that a recent change introduces separate probabilities for firers moving or stationary. This change was made after the model was examined for this report.]

Vehicle Casualties

A vehicle is counted as killed or not after random number selection. The probability of kill, given a hit, is a user input based upon weapon. ammunition, and target vulnerability class. Whenever the random number comes out less than or equal to the input probability, the vehicle is killed. Each round that strikes the vehicle is treated separately -- there is no accumulation of probabilities from one round to the next.

Under no circumstances can more than one vehicle be destroyed in any single firing (one unit firing one weapon type at one target unit). One must remember that CARMONETTE is a small unit simulation and the internal logic is so defined. The user should not assume that he can simulate a unit of four aircraft firing missiles at a unit of four tanks. The model would, in effect, have each aircraft firing at the

same tank. And, in retaliation, each tank would fire at the same aircraft. This logic is purposely used in the model, since the documentation states that "precluding the destruction of more than one vehicle when several hits are scored eliminates the perfect distribution of fire and inter-communication among the elements of a firing unit that the alternative implies."

Perfect distribution seldom occurs, but such absolute nondistribution is hardly better, nor is it the only alternative. It would seem relatively simple to have each projectile "randomly pick" one of the possible targets. This would seem a more accurate simulation of actual target acquisition, and would imply no intercommunication among elements of the firing unit. This proposed logic can be introduced without difficulty. Yes

If a vehicle is killed, the driver(s) is immediately assumed to be a casualty, also. If the vehicle is not a troop carrier, all personnel in the vehicle are assumed to be casualties. (Effect on troop carriers is discussed in the next section.) The vehicle is then denoted as dead and, with a user-defined probability, may indicate its death by burning, crashing, etc.

Casualties to Mounted Troops

A troop carrier is handled no differently from any other vehicle. The troops inside, however, are considered to be a separate unit, and do not necessarily die with the vehicle. The user must input a probability of survival for the infantry if the vehicle is killed. This probability is based on weapon and ammunition type. A random number is generated for each soldier and compared to this probability of survival. In this manner, the number of troop survivors is determined. It is not clear how the model handles troop casualties from vehicle hits that did not kill the vehicle.

If there are other troop carriers in this unit, the surviving troops will attempt to board these carriers. If there is insufficient space to accommodate the survivors, all troops will dismount from their carriers and proceed on foot. This is a questionable tactic, but the only alternative in the simulation is to allow no survivors that cannot be accommodated on other carriers. Both approaches have their disadvantages.

Transport helicopters are allowed in the simulation, and are designated as mobility class 7. No special logic in CARMONETTE relating to this mobility class is to be found, and so it is assumed that the transport helicopter is denoted as a troop carrier in input. If this assumption is true, two major problems are encountered. First, no distinction is made for carrier type when entering survival probabilities. Hence, an infantryman would have the same chance of surviving a helicopter crash as surviving a damaged APC. Secondly, the logic described above for troops remounting other carriers would be entered, and that is not easily accomplished while flying. Nor would all the troops in a unit of several helicopters normally be expected to dismount and continue on foot if one helicopter were lost. It appears that the model does not logically expect a transport helicopter to be killed.

The documentation is lacking in its treatment of scout and transport helicopters. The program itself seems to show an underlying assumption that these vehicles are immune to enemy fire. If they are expected to remain behind friendly lines, away from enemy fire, it should be so stated in the documentation.

Effect of Indirect Fire on Vehicles

Versions 4 and 5 of CARMONETTE were revised to allow the possibility of indirect fire weapons killing vehicles. The probability of kill is input by the user based on the weapon, the ammunition, and the target vulnerability class. Basically, this probability is computed by dividing the vulnerable area of the vehicle by the impact area of the weapon. These probabilities are, of course, very small.

Should the damaged vehicle be a troop carrier, troop survivability is computed as in the previous section. Probability of troop survival in carriers is input under vulnerability Class 12.

Casualties To Exposed Infantry -- Fragmentation Ammunition

For each weapon capable of firing fragmentation ammunition, the user must input the probability of killing infantry based on the infantry posture and the net cover provided by the terrain. If the infantry unit

is responding to previous enemy fire, he will button up and present a smaller target. The user also defines three net cover indices based on the element size and the cover and concealment of the grid square occupied by the infantry unit.

The user must externally compute his kill probabilities based on these factors. The method employed is to determine a lethal area for a given weapon, ammunition, posture, and net cover, then divide by the impact area. The impact area is internally defined as one grid square for direct fire weapons, and is user-defined (from 1 to 9 grid squares) for indirect fire weapons. One basic assumption in this method is that the infantry unit occupies only one grid square, and is uniformly distributed in that grid square. When the battlefield is scaled up or down by varying the grid size, the impact areas will change. This point needs to be investigated to see if corrections are applied or are needed.

Again, a random number will be generated for each infantryman in the unit and compared to the kill probability. If the soldier is killed, his weapon is also killed.

All units in the impact area of an indirect fire weapon undergo attrition and suppression as a result of that fire. Direct fire weapons, however, are assumed to have a specific target, and will not hit other units in the grid square. This is true regardless of the grid size and lethal area of the fragmenting ammunition. Other units are suppressed by such fire.

Casualties To Exposed Infantry -- Nonfragmentation Ammunition

For machine gun and rifle fire, the calculation of infantry killed is somewhat different. The probability of kill given a hit is input. Infantry are assigned to a certain vulnerability class, and their weapons do not have multiple kill capability.

Assume that a rifle squad fires a volley of ten shots at an enemy infantry squad of eight men. The firing accuracy routine might determine that six of the ten shots were hits. The kill routine would compare each hit against the kill probability (given a hit) to determine the number of

killing hits. Another random number is generated to determine which of the eight men received each killing hit. In this manner, an enemy infantryman may be hit and killed by multiple projectiles. This manner of distributing fire is far superior to that discussed in the vehicular section.

EVADE

Ground Sites

Two distinct options are available for air-to-ground fire: (1) Accuracy and vulnerable area tables, used with the SALVO equations, yield a probability of kill and (2) probability of kill tables, where the single-round kill probability is entered and the expected number of kills is found after considering the number of rounds fired.

Based upon the results of the kill probability calculations, a determination is made as to whether the target was suppressed or killed. At a predetermined point (input value of kill probability, typically 0.9) targets are removed from play. The probability level needed to effect suppression of the target is not specified in the documentation; it is an adjustable input quantity.

damage always cumulative

It is questionable whether the results of all firings should always be cumulative. It should depend upon such factors as the damage category, the existence of multivulnerable components in the target, and the results of damage assessment which might be available to the attacker between engagements. For example, a ground unit still firing after an engagement might deserve to have its accumulated kill probability reset to zero before the next engagement. as [illegible] must use the expected value of the outcome

Aircraft

Each ground weapon is checked against each flight path to determine which of the aircraft are possible targets, to determine their priorities, and to then make the target assignments.

A check is made for continuous missile lock-on. The effectiveness evaluation for missiles is then made by a table look-up. This table is a function of aircraft type, missile type, and approach angles (azimuth and elevation). The tabular data are generated externally by a missile end game program.

The striking velocity and angle, relative to the aircraft, are computed. The true projectile trajectory from a trajectory table is used, as an option, or a straight line approximation to the trajectory may be used to save computer time. In either case, deceleration of the projectile is considered when computing the striking velocity.

The model does not allow the aircraft to take evasive maneuvers in response to fire. The flight paths are preplanned, but preplanned evasive maneuvers can be included.

Fire on separate vulnerable components of the aircraft is considered. However, if the component separation divided by the range is less then 0.002 the program does not consider it worthwhile to compute a different approach aspect and striking velocity for the component in question (but rather uses the values already computed for the aircraft center of gravity). This is well within the static level of the vulnerable area data.

A separated component can affect the kill probability calculation in another more important way, that is by moving the target component off the projectile's mean trajectory path. A second test is made by the program to determine if this shift is large enough to cause a significant change in kill probability. The second test for significance compares the component separation distance to the distance between the aircraft center of gravity and the projectile's mean trajectory path. Due to gun system errors and aircraft maneuver the mean trajectory does not normally pass through the aircraft center of gravity. If the component separation distance is less than 10% of the aircraft's center of gravity separation from the mean trajectory path the program does not consider it worthwhile to evaluate the component as separated. Both of these computation bypass controls are intended to save computer time. If the program user did not wish these computations to be bypassed he could remove the program statements which cause the bypass.

The program computes turn bias for aircraft center of gravity and for the components of the aircraft. Three methods of computing turn bias are available. Method one is a simple geometrical solution. Methods two and three are iterative solutions. The flight segment under consideration is subdivided into smaller segments and the point of

minimum separation between the projectile and the aircraft is computed for each subsegment. These figures are compared with solutions of points where the projectile and the aircraft are equidistant from the ground weapon. This is continued until an acceptable separation is achieved and the best solution is then selected. In the computation of maneuver bias, the following constants are used:

> Acceptable error for distance -- 0.09 meters
>
> Acceptable error for instant of impact -- 0.009 seconds
>
> Max closing rate possible -- 1400 meters/second
>
> Nominal separation between bullet and aircraft -- 300 meters

Three possibilities exist for computing the total vulnerable area of the aircraft.

> The sum of areas projected from each face of a six sided rectangular box.
>
> Armitage's triaxial ellipsoid representation as reported in the Simplified Gun Model.
>
> Computed with ellipsoid approximation as given in the VISDET I Model Report.

For aircraft having multiple vulnerable components the following factors are used in computing kill probability; forced landing probability, and crew vulnerability.

> For CH-type helicopters the kill probability is a function of the single vulnerability attrition rate times the probability of killing both pilots. The forced landing probability includes the probability of losing both engines. The crew casualty probability is a function of the sum of the individual casualty probabilities of the two pilots and the crew chief.
>
> For UH-type helicopters with troops the kill probability is the same as that for the CH-type helicopters. The crew casualty probability is the sum of the probability of casualties of both pilots and both gunners.

All other aircraft are handled in a similar manner.

The evolution of the results of ground fire on aircraft appears to be quite complete. It may, in fact, be unnecessarily detailed. It would appear that the model developers had the greatest amount of data and expertise in this area. This subroutine may warrant more detailed study for consideration in other models.

GLOBAL

Two stochastic methods, represented by subroutines HITMIS and NEWHIT, are available for evaluating damage and sustaining the simulation. In addition, parameters for missile and burst fire missions are written onto magnetic tape by subroutines HITMIS and NEWHIT, respectively, for subsequent processing in the analytical gun model. The gun model is simulated in an ancillary computer program (DAMAGE) used to reduce the statistical variability in damage assessment.

The methodology of subroutine HITMISS is used to evaluate the result of single shot firings such as the TOW missile or main tank gun against both air and ground targets. In addition, this subroutine provides the capability of processing bursts from a rapid fire weapon system as single shots.

The first major step in subroutine HITMISS is the selection of a hit probability from an appropriate table defined by firer weapon type, target type, range interval, terrain type, and aspect angle -- front, side, and rear if an aircraft is the target. Only the front aspect is considered for ground targets. Linear interpolation is used for impact angles other than 0, 90, and 180 degrees if an aircraft is the target. A stochastic decision is made to determine whether or not a hit has occurred. The result of a hit against a ground target is assessed either as a kill or partial damage depending upon the aircraft and weapon type. Partial damage is simulated for ground targets by the attrition of one crew member in a crew-served ground weapon. If a miss occurs against a ground target, the burst is further evaluated by selecting a suppression probability from an appropriate table defined by firer weapon type, target type and range interval. A stochastic decision is made to distinguish between miss and suppression. If suppression is assessed, the ground unit will not be able to detect, select, or fire at targets until a suppression delay has been satisfied.

If a hit is stochastically assessed against an aircraft, another stochastic decision is made to distinguish between kill and partial damage using an appropriate probability table defined by firer weapon type, target type, range interval and aspect angle. If the assessment is partial damage, another stochastic decision is made using a selected probability from an appropriate table defined by firer weapon type, target type, range interval and aspect angle to distinguish between types of partial damage, loss of firepower or loss of motion.

The methodology of subroutine NEWHIT is used to evaluate the bursts from rapid fire weapon systems, both air-to-ground and ground-to-air. Aiming and ballistic errors are computed for a rapid fire weapon system using one of three computational options reflecting the aiming and ballistic errors associated with that weapon and target type:

Optical and/or full solution radar formula

Range only radar formula

Specification of mil errors in the input data

If the target is a maneuvering aircraft, the aiming error variance is adjusted by adding a maneuver error variance.

The presented area of the target is taken to be the cross-section normal to the line-of-sight. The particular aspect exposed and the amount of area exposed in each aspect are functions of the aircraft heading, pitch, roll, and line-of-sight.

The hit probability per round in the burst is computed using a bivariate normal distribution originally centered at the target. Two random numbers are drawn to translate the x and y coordinates of the burst center from the target, using the aiming error variance adjusted for a maneuver error variance in case the target is a maneuvering aircraft. The variance of the translated bivariate normal distribution in both x and y directions is given by the ballistic error variance. Direct integration over the presented target area yields a hit probability for each round in the burst. In order to facilitate the integration, the generally irregular target area presented at impact time is replaced by

a rectangular area with length four times the width but encompassing the same total presented area. A random number is drawn reflecting the cumulative binomial distribution to determine the total number of hits over all the rounds within the burst.

The exposed area in each of the presented target aspects is allocated to the various vulnerable damage areas for the target using vulnerability percentages selected from appropriate tables. Tables of vulnerability percentages are input to GLOBAL by target aspect, burst impact velocity interval, and target vulnerable-damage area. The exposed areas in the presented target aspects are allocated to the vulnerable damage areas of the target, summed over all the presented target aspects, and converted to a total percentage of the presented target area for each vulnerable damage area of the target. Then a new random number is drawn for each of the hits within the burst to determine which vulnerable damage area was hit based upon the uniform distribution. Thus hits are allocated to the vulnerable damage areas of the target according to the percentages of the total presented target area that lie in each vulnerable damage area. The different types of damage that have resulted from the hits within the burst are than tabulated. A cumulative record of the damage sustained by the target in the game is updated to the current time interval for singly vulnerable damage areas and multiply vulnerable damage sets. The following damage can result from a burst firing mission:

Miss

K-kill

Forced landing (aircraft)

Mission kill (aircraft)

Components of multiply vulnerable damage sets hit (aircraft)

Suppression (ground targets)

Hit with no damage

After all game units have been processed and subsequent damage assessments have been made, weapon status updates are made by the GLOBAL "update subroutine." This subroutine updates the position and status of all game units according to events that have occurred in the current increment of time. In terms of attrition, a cumulative record of the damage sustained by the target (weapons system) in the simulation is updated to the current increment of time. Subsequently a historic record of attrition per unit and force is generated.

In GLOBAL's attrition logic, there is a significant breakdown which hinges on the choice of the input time increment length. The run used to illustrate GLOBAL for this review considered the increment of time to be one second. Within an increment of time where attrition or kill events occur, GLOBAL sequentially processes each weapon system. The situation can arise in which a weapon is credited with a kill after it has itself been killed. This condition is seriously amplified as the input variable increment of time is increased. Currently GLOBAL does not have program logic to correct this condition and the potential difficulty has been minimized by using a short time increment of one second. There is no easy solution to this problem, which is characteristic of all time sequenced models. It is recommended that care be used when choosing a time increment longer than one second.

AIR-GROUND ENGAGEMENT MODELS COMPARISON SUMMARY

	CARMONETTE	EVADE	GLOBAL
TYPE MODEL	Monte Carlo simulation	Expected value simulation	Monte Carlo simulation
TYPE ENGAGEMENTS	Air-to-Ground Ground-to-Air Ground-to-Ground	Air-to-Ground Ground-to-Air	Air-to-Ground Ground-to-Air Ground-to-Ground
UNIT CAPACITY	Battalion level ground combat 48 weapon units per side	20 aircraft flight paths (15 a/c on a path possible) 50 ground weapon sites	4 aircraft 32 ground weapon sites
SEQUENCING	Event-stepped	Time-stepped	Time-stepped
CODING	FORTRAN IV Compass	BRLESC 2 FORTRAN IV	FORTRAN IV Compass
COMPUTER	CDC 6000 series	BRLESC	CDC 6000 series
SET-UP TIME	4 to 6 man-months	1 to 3 weeks	2 weeks
RUNNING TIME	10 sec/replication/ 1 min game	90 to 120 min/60 to 90 min game	30 sec/replication/ 9 min game
MAP AREA	16 x 16 km	40 x 47 km	30 x 30 km
GRID SIZE	10 to 250 meters	12.7 meters	10 meters
NO. GRID SQUARES	63^2	approx 10^7	10^8
TYPE WEAPONS	56 (4 per unit)	19	18 (maximum of 36 individual weapon systems)

	CARMONETTE	EVADE	GLOBAL
INPUT	Significant preparation required	Significant preparation required	Most extensive preparation required
FLIGHT PATHS	Generated within program according to input orders	Planned external to program and input as straight-line segments	Planned external to program and input as straight-line segments
LINE OF SIGHT	Checked at some boundary crossings or when aircraft change altitude, using one average elevation of terrain for each intervening grid square	Pre-computed, using actual point elevations of terrain	Pre-computed, using actual point elevations of terrain
DETECTION	Markov chain process used to place target in one of four states of target information	Probability of detection tables which consider varying environmental and target conditions.	Probability of detection tables which consider varying environmental and target conditions
TARGET TRACKING	Information state of each target is updated each scan time	Detailed methodology which includes memory of recently masked targets	Simple methodology which considers an unmasked, detected target as being tracked
FIRING DECISION	An extremely detailed sub-model with many internal assumptions and definitions not documented	Detailed submodel with weapon assignments based on optimum target, closest target, and priority target	Simple submodel with weapon assignments based on closeness, priority, and visibility of target
WEAPONS EFFECTIVENESS	P(h) is computed as a function of dispersion, range, and target area. P(k) is obtained by table-look-up of P(k), given a hit, for each weapon and ammunition combination	An extremely detailed treatment of ground-to-air fire. P(k) is computed as a function of aiming errors, ballistic errors, striking velocity, and vulnerable area	P(h) for each weapon is obtained by table-look-up as a function of range, terrain, and aspect angle. P(k), given a hit, is obtained from vulnerability tables for each weapon and target type

	CARMONETTE	EVADE	GLOBAL
WHERE OPERATIONAL	Ft. Leavenworth (CACDA) Picatinny Arsenal (ECOM) Ft. Belvoir (CDC) General Research Corp.	Aberdeen Proving Ground (USAMSAA) Wright-Patterson AFB (FTD)	Ft. Leavenworth (CACDA) Stanford Research Institute
DOCUMENTATION	Vol I - General Description, 1967 (AD 822400-L) Vol II - Data Preparation, 1968 (AD 827900) Vol III - Operating System and Running Guide, 1968 (AD 825000) CARMONETTE IV and CARMONETTE V, 1971 The above documentation requires updating and revision	Evaluation of Air Defense Effectiveness (EVADE II) Digital Simulation for Aircraft Survivability Vol I - User Manual Vol II, Books 1,2,3 - Analyst Manual September 1972 The above documentation is in draft form, being written under contract by Armament Systems, Inc.	Technical Note No. 6, GLOBAL Computer Simulation, June 1972 The above documentation is inadequate. A complete documentation package is presently being prepared under contract by Computer Sciences Corporation

FINDINGS AND CONCLUSIONS

GENERAL

- Two of the models reviewed lack complete, accurate documentation packages. Specific weaknesses in documentation have been pointed out in this report. CARMONETTE documentation has been a piecemeal effort over several years and requires consolidation, updating, and correction of errors. GLOBAL documentation is nonexistent with the exception of general abstracts on the model. A contract to accomplish the GLOBAL documentation is currently being executed.

- The models reviewed have limited capability of addressing the key m on n issues pertinent to air defense of maneuver units engaged in simultaneous ground-to-ground combat. Nor can they cope with the close air support issues of tactics, use of electronic countermeasures, suppressive fires by escort aircraft, and air-to-air combat in a simultaneous ground-to-ground combat context.

- All three models require a great deal of basic input data. The outputs of the models are very sensitive to these data. The sources and validity of much of these data are questionable.

- The models reviewed do not fit into an overall hierarchy of models which is necessary to give logical consistency to analyses of Army air-ground interactions. The results of model manipulations at one organizational level should be reflected as input to analyses in higher level studies. This need to feed information up and down a models chain is well recognized, but very few links between levels of models truly exist at this time. Some links beginning to take form are a regression analysis technique coupling CARMONETTE with the Division Battle Model (DBM) and a chain consisting of CARMONETTE, COMANEX, and DBM.

CARMONETTE

- The CARMONETTE V model permits representation of many of the factors relevant to the aerial attack of ground maneuver units, up to battalion size, to include artillery suppression of air defense weapons and simultaneous ground-to-ground combat.

- The CARMONETTE V model has an event generation structure that will permit growth of capability.

- The CARMONETTE model is sufficiently economical for routine use.

- Only CARMONETTE permits movement of the defender ground units in such a way that they are continuously available as targets.

- Only CARMONETTE is free of the requirement for preselection of a unique flight path, making evasion possible and providing for some degree of maneuver (through its set-up of alternative paths and "skip" orders).

- CARMONETTE plays suppression of ground units in considerably more detail than do the other two models.

- Dynamic response to fire is done only in CARMONETTE.

- CARMONETTE requires minor changes, updates, and refinements of input data, as pointed out in the "INPUT DATA" section of this report.

- The storage of data by CARMONETTE is very efficient, but is highly machine dependent. Transfer of the model to a different computer would require redesign of the data storage and complete reprograming of the model.

- The use of preprocessors permits good flexibility in setting up different treatments and the use of postprocessors permits the user to tailor the output to his specific needs.

- If an aircraft altitude change is ordered between two grids, the change takes place in zero time while the aircraft is in the center of the initial grid; the move time to the final grid is computed for a constant rate of change of altitude.

- Movement can only be parallel to a coordinate axis or diagonal (45 degrees). This is not generally the best or most realistic route.

- The MOVE routine forces aircraft through logic sections that apply only to ground units, at the expense of some wasted computer time.

- Move times are sometimes artificially adjusted to accommodate the logical cycles of the model (scan time, decision time, etc.).

- Line-of-sight always exists between adjacent grid squares.

- Line-of-sight from aircraft to ground weapons is not checked along the aircraft's flight path when the aircraft proceeds to an ordered destination. In effect, flight is assumed to be at treetop level and far removed from enemy units. This logic prevents realistic simulation of observation type aircraft.

- The CARMONETTE simulation of the pop-up tactic has some questionable logic pertaining to checks of line-of-sight while rising and knowledge of the required pop-up altitude in advance.

- A new line-of-sight check is not made after an aircraft lands. Error can be introduced by the assumption that the intervisibilities remain the same after landing as they were before.

- The pop-up tactic is simulated with a subroutine that is rather inefficient in its handling of LOS checks.

- The whole formulation of transition probabilities between levels of intelligence is neither intuitively nor mathematically apparent.

- A weapon unit in CARMONETTE does not communicate its acquisition of nearest-square information on opposing targets. It communicates only pinpoint or erroneous pinpoint information.

- The RADAR routine needs a more thorough investigation to determine the origin and meaning of certain unexplained constants.

- The VISDET and IMADET routines do not distinguish moving targets from stationary targets.

- The IMADET routine has a local constant (CG = 0.75) used in the computation of received contrast. This constant is not explained or documented.

• The CARMONETTE V detection routines VISDET, IMADET, and RADAR are out of balance with the level of detail in the rest of the model and are comparable to the level of detail in EVADE II.

• CARMONETTE documentation indicates that weapons aircraft are limited to visual target detection, while the model itself has provision for all of the six sensor classes.

• The user provides a probability of loss of nearest square information when line-of-sight is lost. It is not obvious, nor is it shown, how one would determine this.

• The CARMONETTE documentation on the firing submodel is inaccurate, probably by virtue of not being updated as changes were made. Many internal assumptions and definitions were found but not explained.

• There is an unavoidable dependence of hit probability on the grid size selected for the game. This dependence can probably be reduced by careful choice of input dispersion values.

• CARMONETTE has some difficulty in the logic for transfer of troops from killed carriers to other carriers, especially when the carriers are helicopters.

• CARMONETTE documentation does not adequately treat the attrition of scout and transport helicopters.

• There is no queuing of requests for artillery and air support. If resources are not available, the request is dropped by the supporting element.

EVADE

• The EVADE II model is the best model for detailed evaluation of ground-to-air attrition.

• The EVADE II model is too detailed for routine use of its full capability. Certain routine applications not requiring the full capability are being well handled however.

- The EVADE II model handles the lack of a detection routine by building in an additional delay factor, corresponding to detection time, for air weapons. Inputs from field test data or judgment are used for these delay factors.

- The EVADE II model is suitable for the air-ground portion of studies involving the aerial attack of maneuver units which are engaged in ground-to-ground combat.

- EVADE II input routines perform very limited editing of input data by checking the bounds of selected variables. The input routines terminate processing upon detection of the first erroneous datum rather than processing the entire data base and flagging errors.

- EVADE II checks LOS at the end points of each flight path segment and then interpolates to find a point between them where LOS is assumed to be broken or established. This could produce a false LOS history along a path segment if the segment is too long.

- EVADE II does not report the number of attacking aircraft which go free when ground weapon saturation is reached.

- EVADE II uses a cumulative total of kill probability (results of one engagement added to the previous results) to determine kill of ground targets.

- The aircraft attrition routine is very detailed and may be suitable for producing input data for use by other models.

- EVADE II is the only one of the three models to include true tracking of a target aircraft with an opposing weapon system.

- The firing accuracy calculation in EVADE includes a line-of sight check during projectile flight (important when playing a TOW).

GLOBAL

- The GLOBAL model is not suitable for studies involving the aerial attack of maneuver units engaged in groung-to-ground combat.

- The GLOBAL model has very little growth potential without major restructuring:

  Only four aircraft and 32 ground weapon sites.

  Stationary defenders.

  Preplanned routes, precomputed line-of-sight, time sequenced design.

  No transfer of target information between units.

  Rudimentary target tracking.

  Simple firing decision.

- The GLOBAL model has been utilized by the Advanced Attack Helicopter Task Force and may be used by the Source Selection Board for the Advanced Attack Helicopter.

- GLOBAL users must input many of the variables CARMONETTE and EVADE calculate. This is especially true where weapon parameters are concerned. Pregame data preparation is extensive and complex, especially in preparation of attacker path segments and subjective visibility or exposed levels. This pregame activity may be advantageous in some studies, e.g. those studies in which attacker routes are key elements in the analysis.

- Much effort is spent in the program in packing and unpacking since the model maintains all input data in core storage. Each executable statement in the GLOBAL program that requires input, necessitates a highly complex data unpacking logic. The major problem presented by data packing and unpacking in GLOBAL is the lack of consistency. Several elements of different size data are merged together and stored under the same name, thus making the program extremely difficult to analyze or alter. Also, because the data handling techniques utilized

in GLOBAL are specifically designed for a Control Data Corporation computer (60 bits per word), conversion to a different computer would be extremely difficult, requiring almost complete reprograming.

- GLOBAL has the capability to stop the predefined movement of a unit on various contingencies which are defined in pregame preparation; e.g., based on detection and selection of a target, a helicopter might be caused to halt and fire from hover.

- Each flight path segment is designated either masked or unmasked for each ground site, based upon pregame calculations. This information is stored as input.

- The model provides no increase to the probability of detection of those targets that were previously detected and then later masked.

- GLOBAL attrition logic processes all units in a fixed sequence after each time increment of play. This can introduce bias for the longer time increments, e.g., by crediting kills to units which may have already been killed in the same time increment.

RECOMMENDATIONS

Certain recommendations can be made based on the review of the three models of this study. These recommendations should be considered tentative, pending completion of evaluations covering all of the air-ground engagement models. In this context, it is recommended that:

CARMONETTE

- CARMONETTE should be retained and applied to studies involving aerial attack of ground maneuver units of up to battalion size.

- Specific improvement to CARMONETTE documentation should include:

  Flow diagrams for each submodel of the BATTLE MODEL, especially the firing decision submodel.

  Corrections to firing accuracy logic explanations.

  Derivation of information transition matrices in the detection process.

  An explanation of the interdependency of input data.

  The play of scout and transportation helicopters.

  An accurate description of the sensor routines and the meaning and origin of the constants used in these routines.

- CARMONETTE should be improved as follows:

  Improvements in the processing and use of input data should be considered prior to further application of the model to studies.

  Requests for artillery and air support should be queued for some period of time after the initial call.

  Move times should not be artificially adjusted to accommodate logical cycles.

  Changes in aircraft altitude should be accomplished over time rather than in zero time.

Moving aircraft should perform LOS checks upon boundary crossings. As a minimum, the model should perform a check between the aircraft and any enemy unit having an anti-aircraft capability.

The rationale for helicopter "pop-ups" should be reconsidered. LOS checks should be performed at incremental altitudes. Firing position should not necessarily be predetermined.

The routine to calculate the minimum aircraft altitude for LOS to the target should be modified to eliminate wasted computer time.

The choices for size of artillery impact areas should be expanded.

The MOVE routine should be modified to allow more direct routes.

When considering aircraft the MOVE routine should be modified to branch around those logic sections relevant only to ground units.

The RADAR, VISDET, and IMADET routines should be replaced by simplified routines based on the output of the EVADE II detection models or other validated models.

Consideration of target speed should be a factor of detection in the VISDET and IMADET routines, if these routines are used.

The coding should be updated to utilize available software features. In particular, the exponential approximation used in the computation of hit probabilities should be replaced by the FORTRAN library function.

The number of grid squares should be greatly increased to permit larger scenarios without loss of resolution.

EVADE

- EVADE II should be retained and applied to studies involving detailed evaluation of ground-to-air attrition.

- EVADE II should be used to produce input data for calculation of hit probability within CARMONETTE and other lower resolution models.

- EVADE II should be improved as follows:

  The entire data base should be reviewed during preprocessing, so that erroneous data are flagged on each pass through the editing routines.

  An air-to-ground detection routine should be devised, one which would be in balance with the level of detail elsewhere in the model.

  The method for handling suppression of ground unit fires should be improved and/or better documented.

GLOBAL

- No further improvement of the GLOBAL model should be initiated.

- The current GLOBAL documentation effort should be completed.

- Future use of GLOBAL should be limited to support of the Advanced Attack Helicopter Project only until such time as CARMONETTE and EVADE can be used for this purpose.